

OCS Study  
MMS 2004-062

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## **OPERATIONS MANUAL**



Prepared for  
U.S. Department of the Interior  
Minerals Management Service  
Alaska OCS Region  
949 East 36<sup>th</sup> Street  
Anchorage, Alaska 99508

# **USING FORWARD LOOKING INFRARED (FLIR) IMAGERY TO DETECT POLAR BEAR MATERNAL DENS OPERATIONS MANUAL**

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This study received funding from the U.S. Department of the Interior, Minerals Management Service Alaska OCS Region and the U.S. Geological Survey Alaska Science Center.

September 2004

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## INTRODUCTION

Recent research has shown that Forward Looking Infra-Red  (FLIR) imagery can detect polar bear dens despite total snow cover over their denning habitat. FLIR imagers detect a  $\Delta T$  or difference in temperature between objects in the imager's field of view. During the Arctic winter, the ground/snow surface is typically cold, providing a dark background in the FLIR imager. Sources of heat appear as lighter or white areas. Dens, in particular, appear as small bright "hotspots", usually with fuzzy boundaries (Appendix 1). Most commonly, since bears chose deep snow drifts for denning, dens can be distinguished from the normally dark (cold) band of drifted snow surrounding them.

This innovation has the prospective to prevent human activities from disturbing denning polar bears by allowing managers to discover dens before potentially disruptive activities begin. This is important as concern exists that expanding resource extraction in Alaska's Arctic regions may threaten the welfare of polar bears and their habitat. In recent years, exploration and development activities have expanded steadily east and west of the original oil fields of Prudhoe Bay. Hydrocarbon extraction is now occurring or planned along  ch of the central Beaufort Sea coast. As development continues into the National Petroleum Reserve, the scope of expansion could include up to 2/3 of the northern coastal region of Alaska. Industrial activities are a potential threat to polar bears, especially as they might disturb bears in maternal dens (Lentfer and Hensel 1980, Stirling 1990, Stirling and Andriashek 1992, Amstrup 1993, Amstrup and Gardner 1994). As the number of humans and their activities have increased in recent years, there has been a concurrent increase in the number of female polar bears denning on land (Amstrup and Gardner 1994). Therefore, the probability of disrupting maternal denning can be expected to increase in the future. Using FLIR surveys to detect bears in dens could reduce or eliminate that probability.  is manual serves to provide agency and private sector land managers with the  rmation necessary to perform effective FLIR surveys. For additional assistance, a complete contact list is provided in Appendix 2.

## BACKGROUND

Polar bears construct maternal dens of snow and ice throughout their circumpolar range (Amstrup and DeMaster 1988). Hence, denning habitat is constrained to areas of sustained snow deposition or drift. Many known denning areas are concentrated in a few widely scattered mountainous locations such as the Svalbard Archipelago, north of Norway (Larsen 1985), and Franz Josef Land, Novaya Zemlya, and Wrangel Island, in Russia (Uspenski and Chernyavski 1965, Uspenski and Kistchinski 1972).

In the southern Beaufort Sea, terrestrial dens occur throughout the coastal plain of northern Alaska. Previous studies suggested they were most frequent in northeast Alaska and northwest Yukon Territory (Amstrup and Gardner 1994). In the last decade, however, maternal dens have been increasingly common in all areas of the Beaufort Sea coast. Much of this region is currently being considered for, or is undergoing, petroleum exploration and extraction. Oil exploration and construction generally occur during winter when disruption of tundra habitats and most arctic wildlife species are at a minimum. Disturbance to polar bear maternal dens is possible throughout this time, however, and could result in reproductive failure. Knowledge of polar bear den chronology provides temporal boundaries for management of human activities (Amstrup 1993, Amstrup and Gardner 1994).

Spatial management, however, has been more problematic because the location of active dens has been known only retrospectively (visual sighting or capture of new family groups upon emergence or telemetry data). Sufficient snow accumulation, which is important for the establishment of maternal dens (Harington 1968, Lentfer and Hensel 1980, Kolenosky and Prevett 1983, Amstrup and Gardner 1994), is dependent on topographic features such as banks and bluffs (Belikov 1980, Lentfer and Hensel 1980, Benson 1982). Recent mapping efforts have revealed the locations of preferred denning areas in portions of the Alaskan North Slope (Durner et al. 2001, 2003, Figure 1). The availability of digital maps of preferred denning habitats allows land managers to plan their activities in order to avoid areas likely to hold dens. Sections of preferred habitat, however, may not be avoidable for all work scenarios. A method to detect the presence of active den sites is highly desirable for situations where favorable habitat and

development or exploration overlap. In this manual, we provide guidance for using FLIR imagery to search for polar bear dens in habitats within or adjacent to human activities that could disrupt denning polar bears.

The manual is comprised of two principal components. First, we describe the results of tests performed to evaluate the effectiveness of FLIR in detecting dens. This research summary provides the technical information learned during our recent evaluation of FLIR with known polar bear dens. These results provide the information from which useful operational FLIR surveys might be developed. The second component of the manual is an outline of operational considerations necessary for those who conduct FLIR surveys in future management applications. This outline presents the critical elements of a FLIR survey, discovered during our research, in chronological order. The outline takes development of the FLIR survey from initial questions of whether FLIR is appropriate to survey preparation, through conducting the survey and reviewing tapes. The outline culminates with the process of making a “positive finding” decision and associated recommendations regarding images detected on FLIR surveys. While referencing the resulting research, the outline provides a “how to” guide for performance of FLIR surveys that will be useful in managing human activities so as to minimize impacts on denning polar bears.

## **I. FLIR STUDY RESULTS: An Overview**

In order to test whether FLIR imagers can detect polar bear maternal dens, we needed to know the locations of dens. We located maternal dens by capturing female polar bears, fitting them with radio collars, and following them to den sites. We tested detectability of known dens by flying over their locations with FLIR equipped aircraft. We modeled flight and weather conditions most conducive to den detection with logistic regression.

### **Locating Dens**

We captured solitary adult female polar bears by injecting immobilizing drugs [tiletamine hydrochloride plus zolazepam hydrochloride (Telazol®, Warner-Lambert Co.)] with projectile syringes fired from helicopters (Larsen 1971, Schweinsburg et al. 1982, Stirling et al. 1989). Satellite and VHF radio transmitters were attached with neck collars (Amstrup et al. 2000). Pregnant radio-collared females were followed to dens by a combination of satellite and aerial radio-telemetry. During FLIR surveys of radio-collared bears, we detected additional previously unknown dens.

### **Surveying Dens**

We tested the effectiveness of FLIR Safire AN/AAQ-22 by flying transects over known dens. The Safire, which operates in the 8-12 micrometer ( $\mu\text{m}$ ) wavelength range can, according to the operations manual (FLIR Systems, Inc. Portland, OR), detect differences in temperature down to  $0.1^\circ\text{C}$  under ideal circumstances. The Safire was Gimbal mounted under the nose of a Bell 212 helicopter. This mounting system allowed the imager to be directed independently from the attitude of the aircraft and in any direction below the horizontal plane of the aircraft.

We tested the FLIR imager in transect and hover flight modes. Although we knew the locations of dens used for our tests, we used knowledge of the terrain to fly transects as if we were searching likely habitat for unknown dens. Transect routes were flown parallel to principal bank habitat features. We attempted to orient the aircraft so that the prominent snow drifts likely to hold dens were below and to the side of the aircraft. This oblique view allowed us to focus the

FLIR approximately perpendicular to the face of the drifts we were searching. Transect flight mode simulated flight patterns that might be used in operational surveys for unknown dens. Rather than simply flying to known locations where radio-collared bears were denning, we surveyed portions of bank habitats at least 1 mile either side of the known den. During November of 2001, we also flew transects over extensive lengths of bank habitat where no collared bears were known to be denning that year, but where dens had been detected in the previous 2 years. Surveying banks not associated with radio-collared bears provided some opportunity to detect dens of unmarked bears. When a known den or otherwise suspicious hotspot was seen on transect, we attempted to hover or circle over the spot at a variety of altitudes to adjust the image, and determine whether we were seeing a den or some other source of heat differential. After both flight modes were completed, known dens were recorded as detected or not. In addition to scoring detection as yes or no, we recorded the weather conditions at each survey occasion. Recorded weather data included ambient temperature, dew point, relative humidity, wind speed, wind direction, percent cloud cover, cloud ceiling elevation, visibility, presence or absence of blowing snow, airborne ice crystals, falling snow, fog, and other detectable airborne moisture. We also recorded whether or not sunlight was impacting the ground where we were surveying.

In the spring, after den emergence, we attempted to visit each den located the preceding winter. During those visits, we recorded the size and shape of the den, the amount of snow overlying the lair, the nature of the habitat surrounding the den, and the slope and aspect of the drift feature holding the den. We also attempted to visit many of the dens in the summer after snow melt. At these visits, we were able to record additional characteristics of the den location and also to look for evidence of the denning activity that may have been left in the soil or vegetation (Durner et al. 2003)

## **Analyses**

Data were tabulated and sorted with an Excel (Microsoft, Inc., Seattle Washington) spreadsheet. Analyses were performed using program S-Plus (V. 2000, Mathsoft, Inc., Seattle, WA), and SAS (V. 8, SAS Institute, Inc. Cary, NC). Descriptive statistics were calculated and all variables were

cast in a Pearson correlation matrix. We tested for frequency differences in individual categorical variables (e.g. presence of airborne moisture or sunlight [yes or no]) between occasions when dens were detected and when they were not, with Chi-Square goodness of fit tests. Differences in values of individual continuous variables (e.g. cloud cover or ceiling) were tested with the Student's T-test.

We modeled detection of dens, in a multivariate context, with logistic regression. Although most FLIR images were acquired during darkness, eight attempts to detect dens were made at times after which sunlight had begun to light up the snow surface. No dens were detected during these 8 attempts. Logistic regression breaks down when responses associated with a single level of a categorical variable are either all “successes” or all “failures.” Therefore, we eliminated FLIR video acquired during sunny conditions and modeled detection with a logistic regression that applied only to non-sunny times. We used a stepwise regression procedure (Neter et al. 1996, Ramsey and Schafer 1997) to build a final logistic regression model (McCullagh and Nelder 1989) describing the probability of seeing a polar bear den on FLIR video, given the weather and environmental conditions present at the time the video was recorded. After removing the 8 observations associated with sunny conditions, 59 observations were available for this model fitting. The list of covariates considered during the model building process is provided in Table 1. At each step a single variable could enter the model and one could leave the model. We used a significance level of  $\alpha = 0.10$  of the Score Chi-Square test incorporated into SAS Proc Logistic, as the cut-off for exit and entry into the logistic model.

Because the coefficients in logistic regression are not directly reflective of the magnitude of the response (like they are in linear normal theory regression, for example), we calculated Odds and Odds Ratios. In logistic regression the outcomes are either 0 or 1. “Odds” is simply the probability of getting a “1” (which is the estimate of  $\hat{P}$ ) divided by the probability of getting a “0” (which is  $1 - \hat{P}$ ). In this FLIR application, the odds of seeing a den given that one was present ( $= \text{Pr}(\text{den seen}) / (1 - \text{Pr}(\text{den seen}))$ ), were computed. Then, to help explain the role of covariates in the final model, ratios of odds (odds ratios) of seeing a den at one level of a



covariate to the odds of seeing it at the next incremental level of the covariate (e.g. odds of seeing a den when temperature-dew point spread = 2 versus when it equals 1) were calculated.

Because sun was omitted from the logistic modeling, we estimated probability of identifying an occupied polar bear den during sunny conditions with a 95% confidence interval constructed by inverting a one-sided binomial hypothesis test (Lehmann 1986, p. 93). To compute the upper value of the confidence interval, this method involved iteratively guessing at the value of an upper bound,  $p_u$ , until the hypothesis  $H_0: p \geq p_u$  was just rejected at the  $\alpha$  level of significance in favor of the hypothesis  $H_1: p < p_u$ . For example, assuming  $n$  (here,  $n=8$ ) FLIR videos were recorded during sunny times, and biologists could identify occupied polar bear dens on  $a_0$  of those  $n$  videos (here,  $a_0 = 0$ ). The upper  $(1-\alpha)\%$  confidence limit was the smallest value of  $p_u$  that satisfied the condition for rejection of  $H_0$ , i.e.,

$$\sum_{x=0}^{a_0} b(x, n, p_u) \leq \alpha .$$

where  $b(x, n, p_u)$  was the probability of observing  $x$  successes in  $n$  trials from a binomial distribution with probability  $p_u$ ,

$$b(x, n, p_u) = \frac{n!}{x!(n-x)!} p_u^x (1-p_u)^{n-x} .$$

We recognized the possibility that interactions could have occurred between sunlight and the other covariates considered in our logistic model. We also recognized the shortcomings of not including sunlight in our overall logistic regression model. Therefore, we evaluated the binary response of “detected” versus “not detected” using an empirical logit transformation and a normal theory regression model that included sunny and non-sunny conditions. This analysis involved transforming the binary yes/no response (yes = den seen on video, no = den not seen)

using the empirical logit transformation:  $f(y_i) = \ln\left(\frac{y_i + 0.1}{1 - y_i + 0.1}\right)$ , where  $y_i = 1$  when a polar

bear den was seen, and 0 when it was not seen. This transformation allowed the use of normal theory (linear) regression, to fit a model describing the probability of identifying an occupied

polar bear den given certain environmental conditions. This empirical logit transformation allowed inclusion of the 8 observations during sunny conditions. After the above transformation, a stepwise procedure was used to fit the multiple linear regression model. We used a significance level of  $\alpha = 0.10$  as the cut-off for exit and entry into the model. Odds ratios again were computed to aid interpretation of coefficients in the final model.

## Results

During this study we located 19 polar bear maternal dens on land by radio telemetry. Bad weather, poor quality radio fixes, difficult terrain, and a malfunctioning tape player prevented us from securing FLIR images at 4 dens of radio-collared polar bears. During attempts to view the 15 remaining dens, we observed 12 previously unknown hotspots that we concluded, either in flight or upon subsequent review of FLIR tapes, were polar bear dens. Dens (and targets presumed to be dens) appeared as small bright (hot) spots, usually with soft boundaries, within a normally dark (cold) band of drifted snow (Appendix 1). Spring and summer surveys confirmed that 3 of the unknown hotspots were not polar bear dens. Thermal differentials we detected at these sites were the result of 1) an empty steel barrel, and 2) a large boulder partially embedded in an unstable permafrost bank and 3) a piece of sloughed tundra lying partway down a permafrost bank. We failed to obtain evidence confirming whether a 4<sup>th</sup> unknown hotspot was a den. This hotspot had all the earmarks of a den, but despite 2 winter images, we were unable to return to this site in either spring or summer to search for evidence of polar bear use.

We surveyed the other 23 dens or hotspots on 67 occasions (1 to 7 times each). The number of viewing occasions was inversely proportional to the distance of the den from the home base of the helicopter used for FLIR surveys. Four dens (17%) were never detected with FLIR. Two of these were visited on 2 occasions; the other two were visited only once. One den visited twice was detected both times. Two dens visited once each were detected on those single visits. Detection of the other dens was mixed. Figure 1 summarizes the frequency of detection for the 23 dens surveyed at least once.

## Univariate Comparisons

We used the Student's two-sample **T** test to compare the continuously distributed covariates wind speed, temperature, temperature dew-point spread, cloud cover, cloud ceiling height, and maximum reported visibility, at times when we detected known dens versus times we didn't detect them. We also compared depth of snow over the lairs of dens that were not detected to the depth over dens that were detected. When evaluated singly, in the two-sample T context, only wind speed and temperature dew-point spread differed significantly between detection and non-detection events. The mean wind speed (11 kts/hr) on occasions when we didn't see dens was significantly higher than on occasions when we did see dens (6 kts/hr) ( $t = 2.897$ , d.f. = 65,  $P = 0.0051$ ). Similarly, the mean spread between temperature and dew-point on occasions when dens were not seen (2.56 °C) was significantly narrower than the mean spread (3.01 °C) when dens were seen ( $t = 2.891$ , d.f. = 65,  $P = 0.0052$ ).

It stands to reason that the depth of snow over dens is directly related to the degree to which the heat from a bear is insulated from the snow surface. The range of depths recorded for dens in this study, however, was apparently below any threshold that prevents detection by FLIR. Although the differences were not significant ( $t = -1.001$ , d.f. = 18,  $P = 0.383$ ), the mean depth over detected dens was 40cm while the mean depth over dens that were not detected was only 31cm. Also, the greatest depth (96cm) was recorded over a den that was detected both times it was surveyed.

Two covariates were recorded simply as present or absent at each FLIR occasion. Airborne moisture included blowing snow, falling snow, fog, mist, or ice crystals. If any of these conditions, either singly or in combination, were detectable, Airborne Moisture was recorded as yes. If none were present, Airborne Moisture was recorded as no. Similarly, if the sun was above the horizon and shining on the snow surface (even with cloud cover present), the variable Sun was recorded as yes. Airborne Moisture was detectable on 12 of 23 (52%) occasions when dens were not seen and on only 15 of 44 (34%) occasions when they were seen. A chi-squared contingency table, however, suggested this difference was not significant ( $\chi^2 = 2.06$ , d.f. = 1,  $P = 0.152$ ) indicating that the presence of air moisture didn't, by itself, explain detection of known

dens. Sunlight was present on 8 of 23 (65%) occasions dens were not seen, and on none of the occasions dens were seen. This difference was highly significant ( $\chi^2 = 17.38$  d.f. = 1,  $P = 0.00003$ ). The probability of seeing an occupied polar bear den on FLIR video recorded in sunlight was estimated to be 0, with an upper 95% confidence bound of 0.313 (Table 2; (Lehmann 1986, p. 93)).

### Modeling Detection

Some insights regarding the ability of our measured covariates to explain detection by FLIR were obtained from the above individual comparisons. Recognition of possible interactions among our covariates, however, mandated modeling approaches in which all covariates were eligible to enter. The final logistic regression model for the probability that an occupied polar bear den was seen on the FLIR video recorded during non-sunny times was,

$$\hat{p} = \frac{\exp[-2.8576 + 1.1237(\text{spread}) + 1.5692(\text{air\_moist} = 0)]}{1 + \exp[-2.8576 + 1.1237(\text{spread}) + 1.5692(\text{air\_moist} = 0)]}$$

Standard errors for coefficients in the final model were 0.5401 for spread and 0.6846 for air\_moist. The odds ratio for spread was 3.08, indicating that for every 1 degree (°C) increase in the difference between temperature and dew point, we were 3.08 times more likely to see the den. This Odds Ratio was calculated as:

The probability of detecting a den when the spread = 1 is :

$$\begin{aligned}\hat{p} &= \frac{\exp[-2.8576 + 1.1237(1) + 1.5692(\text{air\_moist} = 0)]}{1 + \exp[-2.8576 + 1.1237(1) + 1.5692(\text{air\_moist} = 0)]} = \\ \hat{p} &= \frac{\exp[-2.8576 + 1.1237 + 1.5692]}{1 + \exp[-2.8576 + 1.1237 + 1.5692]} = \frac{\exp[-0.1647]}{1 + \exp[-0.1647]} = \frac{0.848}{1.848} = 0.459\end{aligned}$$

The odds of an event is the ratio of the probability that the event occurs to the probability that the event does not occur, so the odds of detecting a den when spread = 1 is :  $\frac{.459}{1 - .459} = 0.848$ .

However, when the temperature-dew point spread is increased to 2°C, the probability of detecting a den is:

$$\hat{p} = \frac{\exp[-2.8576 + 1.1237(2) + 1.5692(\text{air\_moist} = 0)]}{1 + \exp[-2.8576 + 1.1237(2) + 1.5692(\text{air\_moist} = 0)]} =$$

$$\hat{p} = \frac{\exp[-2.8576 + 2.2474 + 1.5692]}{1 + \exp[-2.8576 + 2.2474 + 1.5692]} = \frac{\exp[0.959]}{1 + \exp[0.959]} = \frac{2.609}{3.609} = 0.7229$$

The odds of detecting a den when the spread = 2 is :

$$\frac{.723}{1 - .723} = 2.61$$

So, the odds ratio for a 1 unit increase in spread from one to two is:

$$\frac{2.61}{.845} = 3.08,$$

Interestingly, odds ratios are easily calculated for each one unit increases in a predictor variable by simply “exponentiating the coefficient value of that predictor variable (raising e to the value of the coefficient), e.g.  $e^{1.1237} = 3.08$ .

Similarly the odds ratio for air\_moist was  $\exp(1.5692) = 4.803$ , indicating that the odds of a trained biologist detecting a den was approximately 4.8 times higher when there was no visible moisture in the air at the time the video was recorded when compared to times with moisture in the air.

Parameter estimates, odds ratios and 95% confidence intervals for the odds ratios are presented in Table 3. Table 4 contains descriptive statistics of the variables in the final logistic regression model. Figure 2 contains the probability of seeing a polar bear on the FLIR video at various levels of the variables in the final logistic model.

In order to incorporate the sunshine covariate into a comprehensive model, we transformed the binary response using the empirical logit. The final normal linear regression model for the probability that an occupied polar bear den was detected on the FLIR video was,

$$f(y) = -5.3273 + 3.3418(\text{sun} = 0) + 0.8555(\text{spread}) + 1.1666(\text{air\_moist} = 0).$$

The standard error for sun was 0.7341. The standard errors for spread and air\_moist were 0.3802 and 0.4699, respectively. Coefficients for spread and air\_moist were approximately the same size in this model as they were in the final logistic regression model. The approximate odds ratio for spread was estimated to be  $\exp(0.8555) = 2.35$  (this odds ratio is “approximate” due to the constant of 0.1 in the empirical transformation). The approximate odds ratio for air\_moist was 3.211. The approximate odds ratio for sun was 28.27, indicating that under similar temperature-dew point spread and no moisture in the air, the odds of detecting a den during non-sunny times was 28.27 times higher than during sunny times. Figure 3 contains plots of the probability of detecting a polar bear den on the FLIR video, as a function of variables in the final normal least-squares regression model. Parameter estimates, standard errors, and p-values for variables in the final normal least-squares regression model are presented in Table 5. Table 6 contains descriptive statistics of the variables in the final normal regression model.

## Discussion

Kingsley et al. (1990) reported that thickness of snow, ambient temperature, wind, and sunlight prevented ringed seal lairs from being detected consistently enough to allow census by FLIR over sea ice habitats. We abandoned attempts, early in this study, to detect dens in the ice environment because of the array of competing heat signatures. FLIR systems detect a difference in temperature between adjacent sites in the field of view. The ocean is a relatively hot environment in the Arctic. Cracks, holes, and pressure ridges created an infinitely variable mosaic of hot, warm, and cold spots in the FLIR screen. Early in the pilot phases of this study, we captured a very clear image from the den of a collared bear high in a pressure ridge of land fast ice. Extremely cold weather and tight ice, along with ideal atmospheric conditions, apparently contributed to that successful detection, because upon later visits, we were unable to distinguish the den from surrounding hotspots. We also failed to differentiate the heat signature of another den on land fast ice that earlier had been visually observed. Similarly, we consistently failed to detect the dens of 2 radio-collared bears denning on drifting pack ice during this study. The heat signatures from these dens may have appeared on the FLIR screen. Due to the abundance of competing hotspots, however, we were unable to know with any certainty whether the dens were among the visible heat signatures.

Although FLIR may not be satisfactory for distinguishing dens on the sea ice, it was effective in detecting dens on land. Bears denning on land are generally surrounded by colder and more uniform substrates than seals or bears occupying subnival lairs at sea. Polar bears also are larger and presumably emit more heat than ringed seals. The potential thermal contrast of denning bears, the uniform backdrop of land and snow, and the FLIR equipment used in this study, combined to create a useful tool for detecting polar bears in their dens in early winter-before construction projects and seismic surveys normally occur. Fortunately, it is those dens on land that are the greatest management concern related to industrial development of the north.

We recognize our FLIR surveys, under the conditions they were carried out, were not 100% effective in detecting dens. We do not expect that the FLIR technology used for this study will

detect all dens regardless of ambient conditions. Future improvements in FLIR technology should be pursued and retested for this application.

However, tempered with the knowledge we provide here, we believe FLIR has an important place in management of human activities that could adversely affect denning polar bears. The 4 dens (17%) we failed to detect during our study were visited a total of 6 times. The first den was initially visited immediately following a blizzard with extensive blowing and falling snow. Surface snow temperatures had not stabilized prior to the flight and the ground surface was extensively mottled with a wind-row pattern of alternate bands of warm and colder snow. Wind speed did not enter our final models of detection. Nonetheless, the wind-row effect on the snow surface often was apparent even when wind speeds were below those that result in obvious blowing snow. This may partially explain the T-test suggesting dens were less detectable under elevated wind conditions. Additionally, this den survey was conducted despite a cloud ceiling of only 400 feet and a temperature-dewpoint spread of 2.2 °C. The only other time we were able to visit this den, the sun was shining. Clearly, neither of these surveys maximized our odds of detecting this den. The second and third dens that went undetected were visited only once each. Those flights both occurred despite airborne moisture visible in the FLIR. Our detection model verifies we were nearly 5 times less likely to see either of these dens than if we had visited them on days without airborne moisture. The fourth den that escaped detection was visited twice. On the first visit, the temperature-dew-point spread was 2.2 °C, less than the mean value for dens that were not detected. The second visit, however, occurred under conditions that should have been favorable for detection-yet we were not able to detect the den.

We cannot know now if added visits under conditions maximizing the odds of detection would have resulted in successful detections of these 4 dens. We do know, however, that 5 of the 6 visits to these dens were during weather and snow conditions that compromise effectiveness of FLIR. Therefore, it is reasonable to think our success rate could have been higher under more suitable conditions.



Logistical constraints prevented acquisition of sufficient data to quantify the probabilities of false positives (calling a thermal signature a den when it is not). It is comforting, however, to recognize that despite flying hundreds of kilometers of FLIR survey, we identified only 3 such hotspots. We are confident that subsequent visits to these sites would have resulted in their removal from our list of suspected dens. Hence, had such hotspots occurred in habitats that were proposed for disturbance, it is likely that multiple surveys would have revealed they were not dens before expensive management measures commenced. Likewise, the one unknown hotspot we were unable to revisit for confirmation purposes, would have been revisited in a real management situation. Our experiences in this study suggest that the risks of false positives are low.

Because of the large areas over which they roam and their low overall numbers, general surveys of polar bears or polar bear dens would not be practical even with new FLIR technologies. We know, however, that denning polar bears occur primarily in steep bank faces along streams, lakeshores, and coastlines of the mainland and some offshore islands. Further, those faces have been identified and mapped across a large section of Alaska's north slope (Durner et al. 2001, Durner et al. 2003). The combination of mapped den habitat and modern high sensitivity FLIR imagery provides the first real tool for detecting polar bears in dens early enough in winter to alter the paths of human activities in order to protect denning bears and humans. With denning habitat either mapped or clearly described, many human activities that might affect denning bears could be routed around those preferred habitats, avoiding the possibility of negative impact. If a road or other development "must" traverse pieces of den habitat, FLIR surveys of the development corridor can help assure minimal population level effect on denning polar bears.

## **II. FLIR OPERATIONS**

### **I. Is FLIR necessary or appropriate to address your management issue?**

A. Like any tool, FLIR is not appropriate for all situations. It is best used under circumstances where disturbance activities are expected to occur adjacent to suitable

bluff habitat in remote locations. There is little utility in conducting a FLIR survey in areas of flat tundra where you would not expect to encounter suitable habitat. FLIR is also not suitable for detection of dens on sea ice (see previous section). A proposed ice road following coastal bluff habitat for many miles or running adjacent to barrier islands would be a good example of an appropriate FLIR project. If you think FLIR may be suitable for your project, consult the denning habitat maps created by USGS (Durner 2000). Layering your proposed activities over the available denning habitat will illustrate areas of possible conflict. Ideally, projects can use these maps in the early stages of planning to simply avoid habitats likely to hold denning bears. Such avoidance could eliminate the need for additional mitigation measures such as FLIR.

B. If the proposed disturbance activity cannot avoid all preferred denning habitat, or if such avoidance would be extremely expensive, FLIR could be used to examine the habitat segments at risk. It is important to recognize that other tools may also be applicable depending upon the situation. For example, if the “at risk” habitat segments are relatively small (the banks on a small coastal island, for example) trained dogs might be brought in to detect polar bear maternal dens. Although sample sizes were small, appropriately trained dogs have been successfully used to confirm the presence of polar bear dens in northern Alaska (Perham 2002). Highly trained scent dogs may be very effective in detecting dens, and because they key in on the scent of polar bears, they are not likely to mark “false positives” (hot spots that look like, but are not dens). Working with dogs, however, has its own logistical limitations. Extreme temperatures limit the amount of time dogs can work without rest and warming, and long distance transport to cover more extensive areas can be problematic.

## **II. Planning a survey**

A. Obtain or create maps of the activity area and proposed developments.

B. Obtain bluff denning habitat maps from USGS (Figure 1 and Appendix 2) available through the following web site:

[http://www.absc.usgs.gov/research/sis\\_summaries/polar\\_bears\\_sis/mapping\\_dens.htm](http://www.absc.usgs.gov/research/sis_summaries/polar_bears_sis/mapping_dens.htm).

- C. Overlay the proposed activities on the habitat maps and note areas of potential conflict- where development occurs within 2 miles of designated bluff habitat.
- D. Select bluff habitat areas of concern, divide those sections into transects, and assign numbers for each transect leg (Figure 2). This will insure that the entire habitat is surveyed and will ease video review.
- E. Make a list of GPS waypoints for the start and finish of each transect and create a map of the habitat and transect lines as noted above. Provide copies to all crewmembers and review prior to the mission.
- F. Choose a survey window that is late enough in the year for bears to have entered dens, but early enough to maximize darkness and minimize snow cover over the dens. (The second week of December through mid-January should be ideal, depending on weather conditions).
- G. Allow enough time to survey the entire area once, return for some point verifications, and account for potential weather days. Once you depart the study area, it is costly to arrange a follow up effort.

### **III. Personnel requirements**

- A. To conduct FLIR missions for the purpose of detecting polar bear dens, it is recommended to have a FLIR operator and two observers.
- B. The operator should be experienced with the FLIR equipment (make/model) available for use and have some experience using FLIR for wildlife or surveillance. Preferably, they will also possess some experience using FLIR under winter conditions.

C. Ideally, the operator, pilot, and the two observers will have some familiarity with Arctic topography. Bluff habitat drifted over with snow and other nuances unique to frozen patterned ground make the use of both FLIR and video imagery challenging. Navigating polygon tundra can be demanding any time of year and is only complicated by snow and ice. The entire crew should obtain copies of existing FLIR video to acquaint, or re-acquaint, themselves with the target imagery and mission techniques. (Appendix 1)

#### **IV. Equipment requirements and settings**

A. To date, FLIR surveys have been conducted with a FLIR Safire II (AN/AAQ-22) thermal imaging system leased from Alyeska Pipeline Service Company complete with four video monitors (two up front and two in rear), and a Sony mini-DV tape recorder. This equipment is stored with Air Logistics, Inc. in Fairbanks, AK.

B. Helicopter choice is dependant on availability and required capabilities. Our testing efforts utilized a Bell 212 outfitted for IFR flight. Since FLIR work should be conducted during VFR conditions (see above), a single engine, single pilot aircraft would also work well and has advantages of reduced cost, increased maneuverability, and reduced noise levels. The primary disadvantage to a non-IFR aircraft is limited operational time due to darkness. Also, weather in the Arctic can change quickly, and the limited VFR windows can close suddenly requiring IFR returns to base camp. Nonetheless, others have successfully used FLIR mounted on Bell 206 and Eurocopter BK117 helicopters in Alaska.


C. A Garmin or comparable GPS should be used for flight track logging. All clocks, including the internal FLIR clock, should be synchronized with the GPS prior to any survey.

D. During our survey development, the FLIR was set to Cage position at the beginning of each transect with the default of: -30 degrees of elevation and 0 degrees azimuth. The following settings were also used: Cross Hairs and Reticules were turned off, Polarity set to white hot, and Gain set to automatic.

E. Use a professional video editing tape deck with frame-by-frame capabilities for tape review. Review is best accomplished using a large format video projector with a projection screen, or using the best available and largest video monitor. Video should be reviewed at the close of each flight session. We detected some dens and hotspots that required revisiting only during tape review. The pace of action, and the vibration caused by the rotors, can result in lack of focus on the FLIR monitor during survey flights. Therefore, the review of recorded tapes each evening after flights is a critical part of the den detection process. Immediate tape review also provides the feedback necessary to flag areas for revisit by the FLIR aircraft.

## **V. Survey Procedures**

A. By necessity, surveys will be conducted during the darkest time periods of the year, in conditions of predominantly “civil twilight”. A chart of sunrise/sunset times for Deadhorse, Alaska during December 2002 is provided for your consideration (Figure 3).

B. There must be adequate light or contrast upon reaching the target area so that the flight crew can visually reference the ground and features of interest. If it is too dark, or flat light conditions exist such that you cannot distinguish bluff habitat or barrier islands, you cannot effectively conduct a FLIR mission. Therefore, FLIR missions must be conducted during the civil twilight of the Arctic  winter or during clear moonlit nights. It is important to note that surveys conducted after mid-February will be marginally successful even if conducted at night. This is due to the solar warming that occurs during daylight which results in considerable IR re-radiation from heated surfaces. The mottled pattern of reradiating surfaces of ice and snow profoundly reduces the ability to distinguish dens from other warm targets (Appendix 1).

C. Remember, polar bears den in areas of snow accumulation or drift- you will be working in a white on white environment. Weather can also delay or terminate a FLIR mission. Ideal conditions for surveying would be clear, calm, and cold. If there is blowing snow, any form of precipitation, or other sources of airborne moisture- use of FLIR is not

advised. Our models of how detection probability varied with environmental conditions revealed that the Odds of detecting a den:

1. Increased 3X for every one degree (C) increase in Temperature Dew-point spread.
2. Were 4.8X higher when airborne moisture (snow, blowing snow, fog etc.) was absent than when it was present.
3. They were approximately 28X higher in darkness than after sunrise.
4. Although not selected by the model, wind speed also appeared to be a significant factor. The mean wind speed (11 kts/hr) on occasions when we didn't see dens was significantly higher than on occasions when we did see dens (6 kts/hr) ( $t = 2.897$ ,  $df = 65$ ,  $P = 0.0051$ ).

D. Crew needs and duties:


1. The team leader should hold a briefing prior to each mission covering plans for that day and any comments from previous efforts. The FLIR team will consist of an operator and two observers.
2. The operator is responsible for the FLIR unit while in flight. He/she should study the FLIR operation manual for the specific unit in use and become totally familiar with its basic functionality, calibration, and use. Prior to a mission, the operator should check that the equipment is operational, the latitude and longitude are displayed on the monitors, and that the internal clock is synchronized with the GPS unit.
3. The two observers should familiarize themselves with the target area (maps) and with IR imagery of the Arctic landscape during winter (pre-survey video review). It will be their job to help keep the aircraft and FLIR over targeted topography. They will also be looking for surface features that may explain a hot spot (dirty snow, exposed soil, ice, etc.). One observer will be designated as the primary data collector- maintaining the flight data sheets and other field notes,

and monitoring the status of the GPS used for recording the ground track of the survey flight. The pilot(s) will also function as additional observers as conditions allow them to participate.

E. Take off procedures:

1. After the aircraft engines have started, turn the FLIR unit on and allow it to warm up. It will go through a series of self-tests in the process. **DO NOT POWER THE FLIR UNIT UNTIL AFTER THE HELICOPTER HAS STARTED ITS ENGINE(S).**
2. Using the calibration menu, adjust the grayscale as per the manual.
3. Stow the FLIR prior to taking off. **LEAVE POWER ON.**
4. Start the Garmin for flight track recording and begin flight data sheet entry.

F. Surveying the Habitat

1.  On reaching the target area, you will need to line up for your first transect leg. Weather conditions at the time of the survey will often dictate the direction of travel and may determine minimum speeds and elevation. However, try to survey each transect in two directions if conditions permit. View angle can be critical in detecting dens and this will provide you with some good additional data for the video review sessions.
2. The aircraft should position itself so that it is somewhat abeam, or offset, of the habitat feature (Fig. X). You will fly parallel to the bluff so that the FLIR is looking into the face of the snowdrift. This will permit the FLIR to capture the

critical habitat in the video window while allowing the observers to visually scan the terrain feature of interest.

3. The elevation should not exceed 800 feet and the speed should not exceed 40 knots.

4. If the aircraft is positioned well, the FLIR image of the bluff habitat will nearly fill the screen. If you are seeing too much of the surrounding habitat (tundra or sea ice) in the monitor, you may want to lower the altitude of the survey. Ideally, the bluff habitat will fill the video monitor with little surrounding habitat showing.

5. Aircraft position and the FLIR view angle can play a significant role in the video quality. A compromised view angle can result in poor image contrast (causing the screen to darken or lighten) making it difficult, if not impossible, to detect faint heat signatures.

6. All transects begin in Wide Field of View (WFV) and adjustments are made to the azimuth and elevation as needed to stay on target.

7. During all transects, repeatedly switch back and forth between IR and video modes. This will help the operator stay on the habitat feature and aid in the interpretation of the video during review at the close of the mission. This method is also critical when you are hovering or circling over a target of interest.

8. When a hot spot is noted, mark the position with a GPS and make a visual record of the area. Return to all observed hot spots upon completion of the transect for hover verification, additional FLIR video, and to obtain an accurate GPS location for future reporting and mapping. Gradually pull into a hover over the location while maintaining a minimum of 200 feet elevation. Make certain to switch periodically between FLIR and Video modes during this procedure, holding in each mode for at least five seconds. The pilot(s) and observers must use this opportunity to visually examine the ground for any surficial disturbance (dirt, debris, and excavation) that may explain the hot spot. This will also provide



an opportunity to use the Narrow Field of View (NFW) functionality to zoom in with the FLIR. Also, try to get as many different view angles as possible on the tape while you are hovering. All of these variations (Hover, Video, Visual, and NFW) provide different and necessary information for later interpretation.



9. Finally, and of critical importance: obtain the best data possible for each hotspot as efficiently as possible. You must always remember to minimize disturbance to the denning bear.

#### G. Landing Procedures:

1. Cage and stow the FLIR unit prior to landing. DO NOT TURN POWER OFF.
2. After landing, power down the FLIR and Garmin units and note the time on the flight data sheet.


### VI. Review

A. Experienced FLIR personnel are required to successfully interpret the video footage. All hot spots are not necessarily of interest. field crew When conducting FLIR video reviews, it is difficult to have too much information from the field. Some questions to consider when reviewing FLIR include:

1. Is this likely denning habitat? Is this bluff habitat? Is there adequate snow depth?
2. Does the hot spot fall within an appropriate area of the bluff? Is it too high on the drift or too low?
3. Is the hot spot associated with a crack or anything visible on the surface (dirty snow, tundra, shape of a drift or other snow feature, etc.)? Does it have a linear character, or is it part of a larger linear feature?

4. Is the hot spot similar in size and shape to other known den hot spots (Appendix 1)?
5. Does the hot spot stand out as 'different' from any surrounding spots or heat sources? (This is not a solid indicator- dens can be associated with other “warm” features that can mislead the reviewers.)

B. Review FLIR tapes as soon as possible after the mission, while still in the field, and with the crew who completed the task. During this review, update the flight data sheets to include as much information as possible from the video, audio, and your collective memory of the mission. It can get hectic in the aircraft and it is subsequently easy to omit information while flying. When reporting on FLIR surveys, it is difficult to have too much information from the field.

C.  mine all tapes thoroughly and with a critical eye. With every possible hot spot, remember to ask the above questions. It is critical to correctly identify all dens, but there are also real consequences for incorrectly identifying a hot spot as a den.

## **VII. Verification**

Any hot spots of interest noted during the tape review, or hot spots needing additional verification should be revisited on subsequent days under good environmental conditions. During these secondary transects, it remains imperative to obtain ample transect and hover footage in both IR and standard video. Observers should once again scan for any signs of surface abnormalities.

## **VIII. Final Decisions**

Ultimately, you will have to make a decision regarding all of the hotspots noted during a FLIR den survey. The information provided thus far should assist in this procedure, however, there will be a subjective component. Tests showed conclusively that naïve observers could not be expected to make sound decisions regarding the nature of hotspots identified in FLIR. Hence, all crewmembers should study existing tape records prior to engaging in fieldwork. The entire

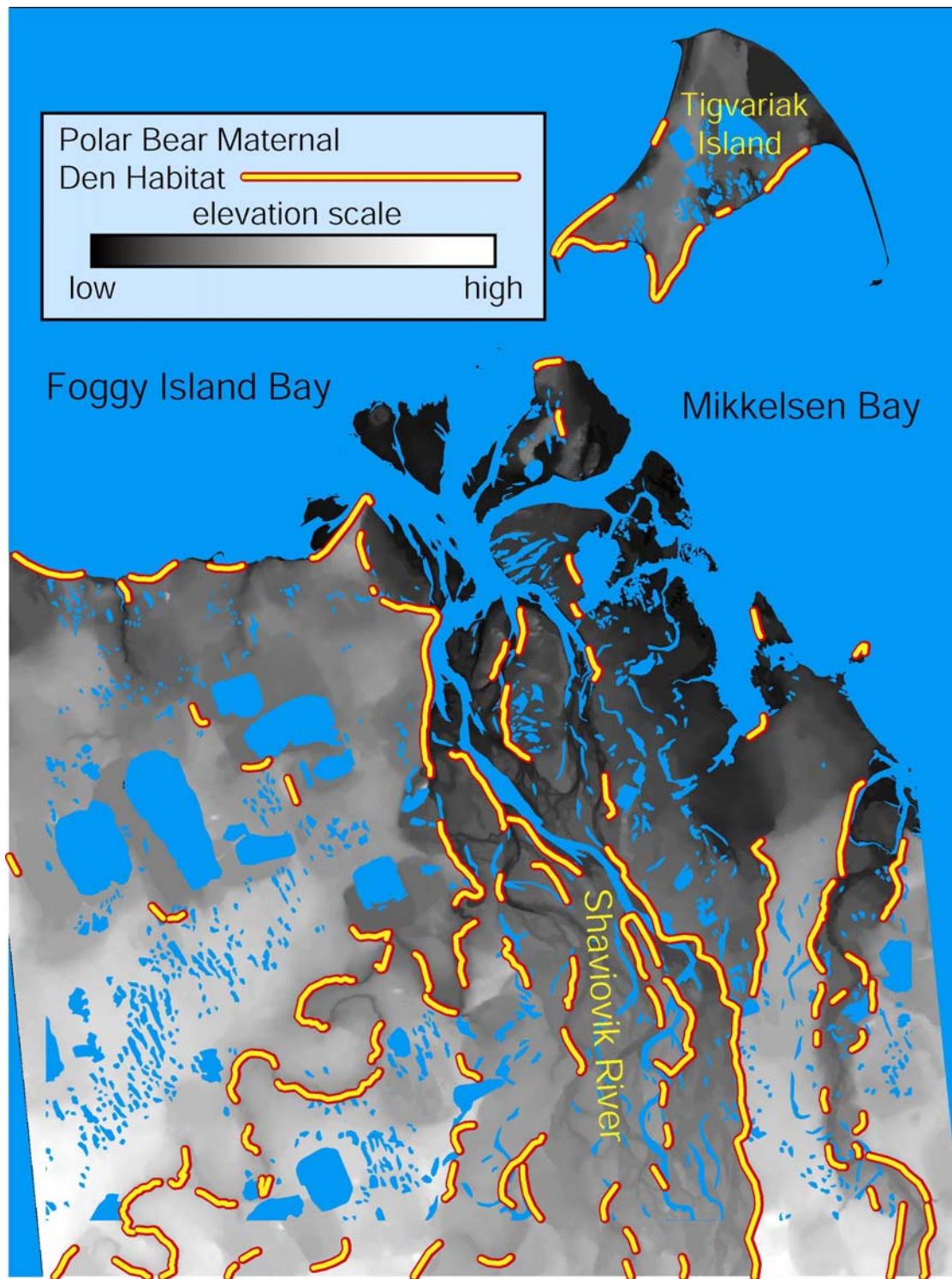
observation crew should also team up during tape review processes in order to render the best and most objective decisions possible regarding detected hotspots.

## **Summary**

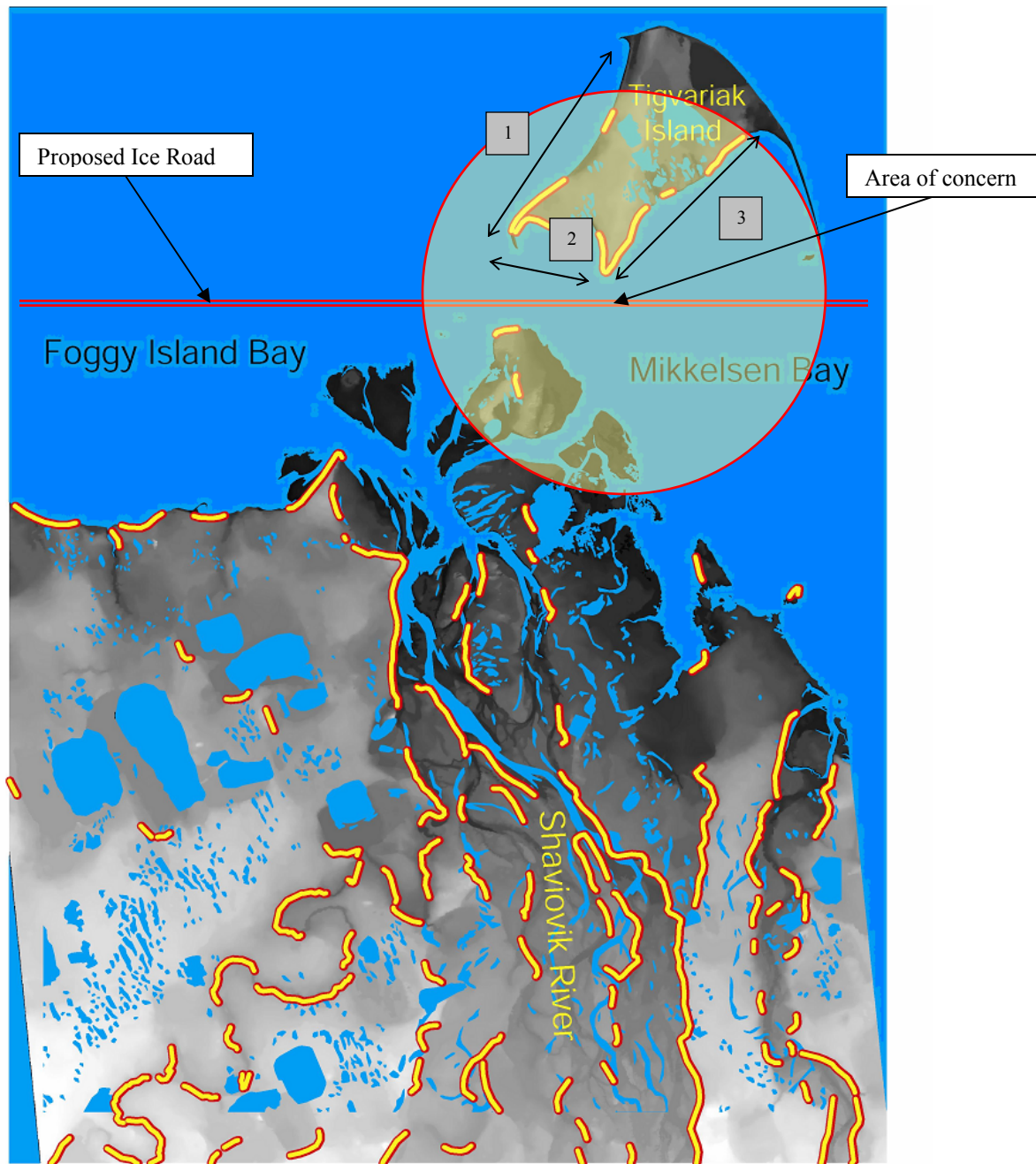
Prior to embarking on a FLIR mission, make certain you have adequate time, personnel, and pre-field planning. During the planning stages, map all development areas and polar bear denning habitat within the region of interest. Refer to these maps when conducting the FLIR surveys and provide abundant related data such as transect direction, altitude, ground speed, weather, and geographic place names in your field notes and on the voice record,. You must have experienced staff on hand and adequate aircraft availability (time for initial survey work and for verification of select spots).

Verify all hotspots seen during transects while in the field. Make every attempt to confirm or deny all hotspots of interest through transect over flights at an elevation not to exceed 800 feet, hovering, plain video footage, and outside observation of the physical environment. Tapes should be reviewed as soon as possible following the mission, preferably that evening. If possible, tape review should be conducted using a projection device that will enable viewing on a large format silver screen. Any "new" hotspots detected during video review must be revisited while the survey team is in the field. FLIR cannot be successfully applied in a hurried manner.

Experienced FLIR operators and observers are critical to the success of this technique. Observers need to have knowledge of the Arctic landscape in winter to effectively evaluate what they are seeing outside the aircraft and on the video monitor. While conducting FLIR survey transects, flip frequently between IR and video to maintain bluff position and give video reviewers adequate perspective. When a hot spot of interest is located: take several waypoints and clearly indicate your geographic location, date/time, altitude, and any additional notes. Make a vertical hover over all significant hotspots to obtain the most accurate location. This also gives the pilot(s) and observers a final chance to discern any obvious surface features or an open hole. This can be achieved at an altitude of 200 feet or greater. Again, make certain that sufficient IR and video footage is taken at all hot spots of interest.



**FIGURE 1:** An example from the USGS polar bear denning habitat map (Durner 2000). Possible den habitat is shaded yellow with red outline.



**FIGURE 2:** This represents a proposed ice road overlain on a den habitat map. The area of concern (determined by U.S. Fish and Wildlife Service) is estimated by the shaded circle. An example of a transect layout is also provided for Tigvariak Island. The lines indicate relative position only, as you would actually follow the habitat in your survey effort.



**APPENDIX 1**

**FLIR IMAGE CATALOG**



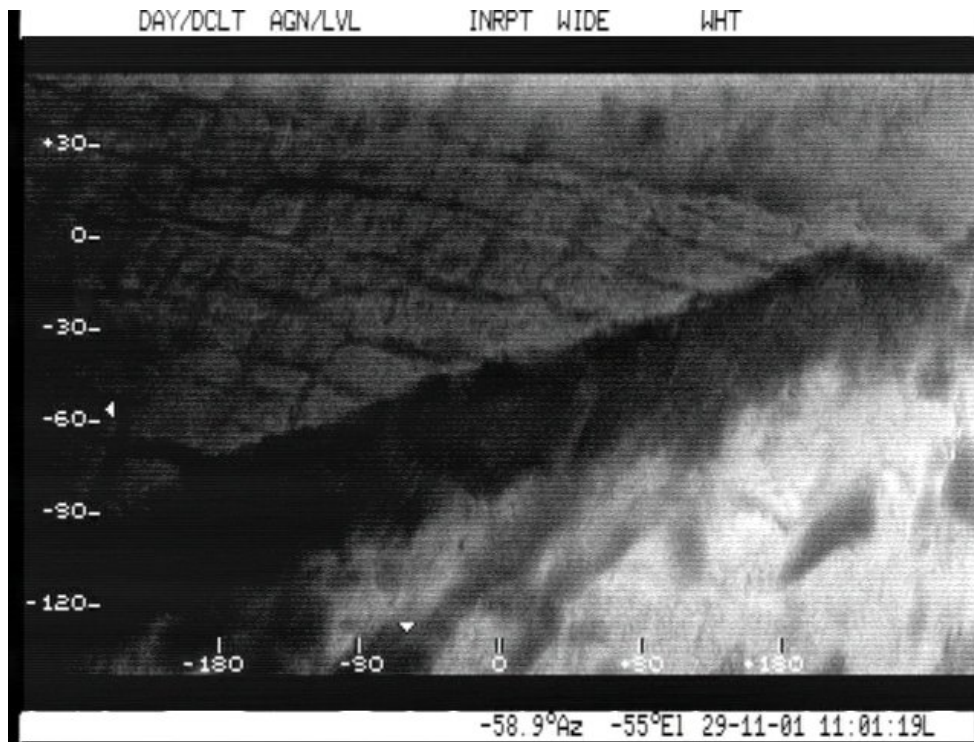


Figure 1: This is a FLIR image of classic bluff habitat. You can clearly see the polygon tundra on top, a cool dark band of deep snow drifted against the bluff in the middle, and the relatively warm, bright sea ice at the bottom of the image. This would be ideal polar bear den habitat, and from the quality of the image, and ideal day to conduct a FLIR mission.



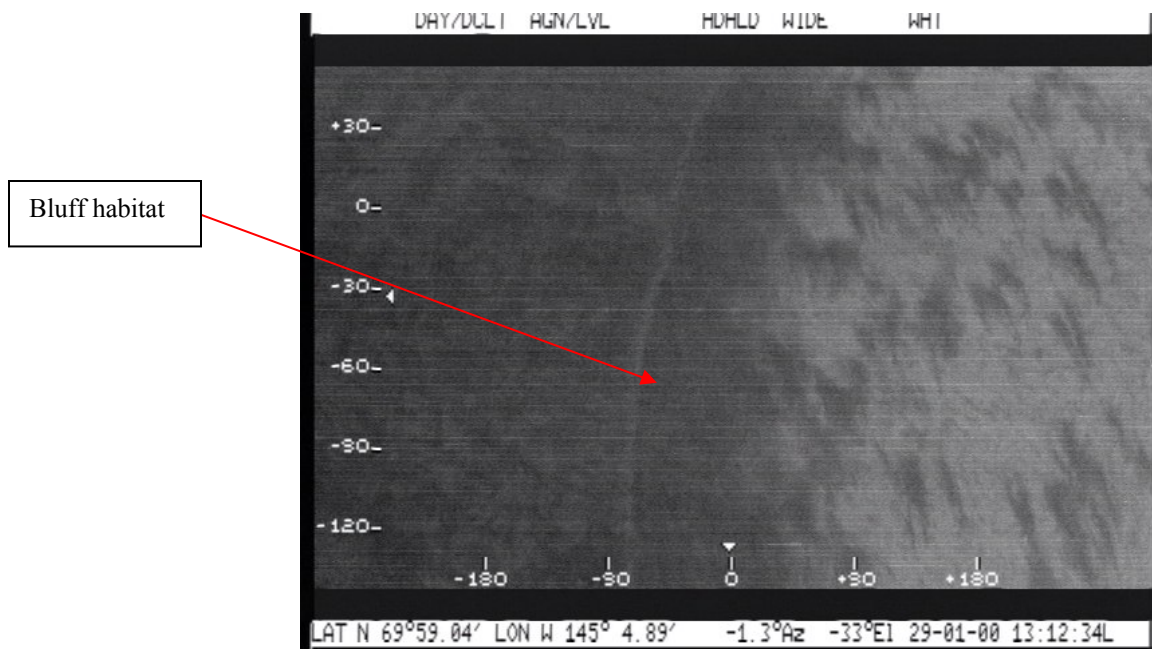


Figure 2: A less clear view of similar bluff habitat. Despite the apparently hazy image, the bluff feature is still quite apparent.

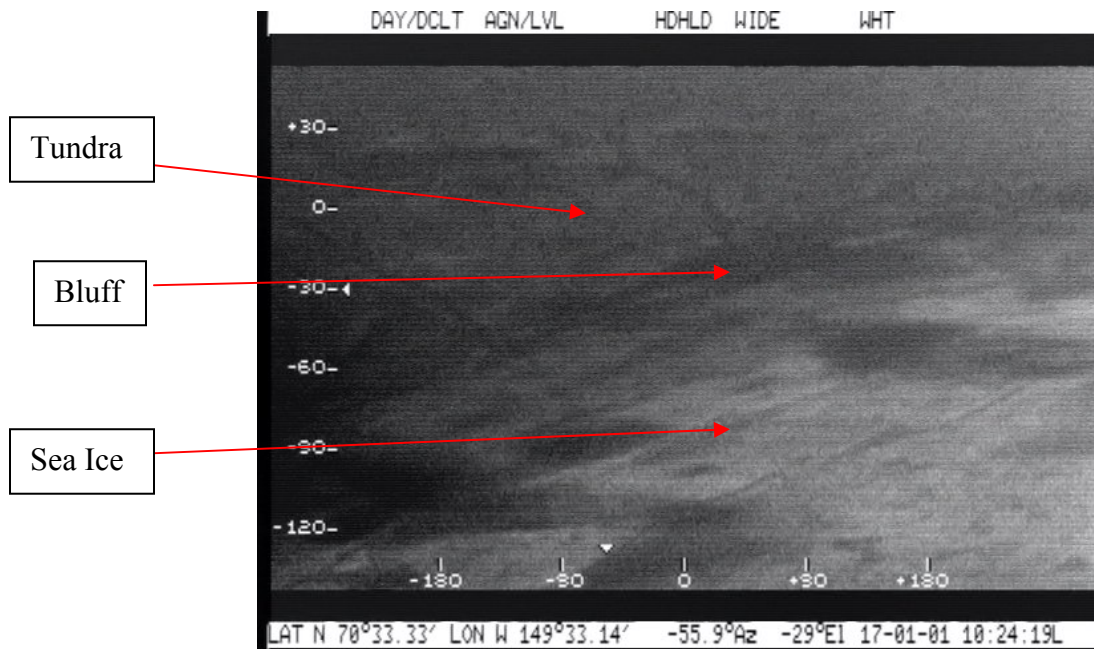


Figure 3: FLIR image of a coastal bluff under conditions where moisture was present in the air. You can still make out the bluff habitat and see some of the polygon tundra.



Figure 4: A classic FLIR den signature in narrow field of view (zoom). You can clearly see the soft warm glow in an otherwise dark area of drifted snow.

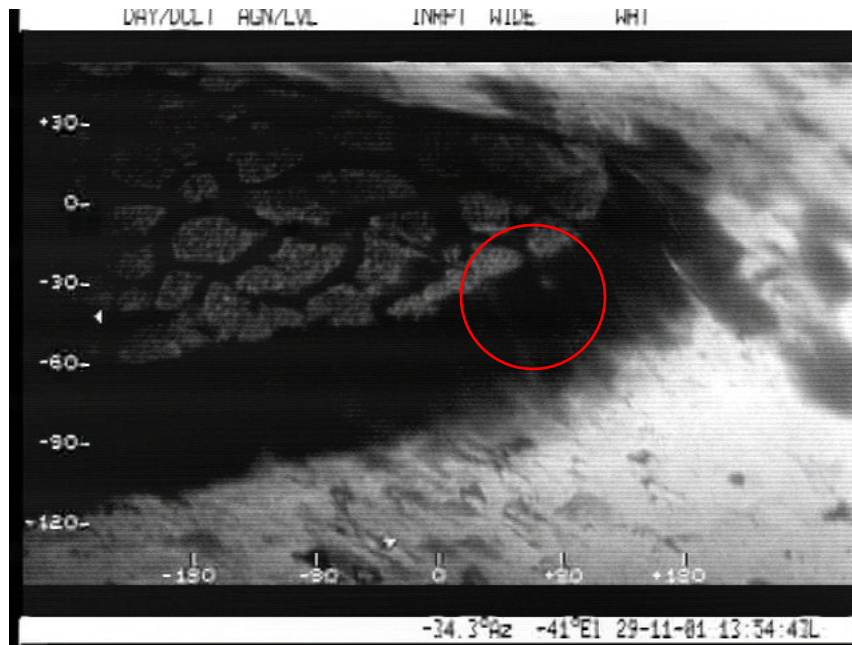


Figure 5: The red circle surrounds the faint den signature from a known bear den along the bluff of a barrier island. Habitat features are very clear in this image.

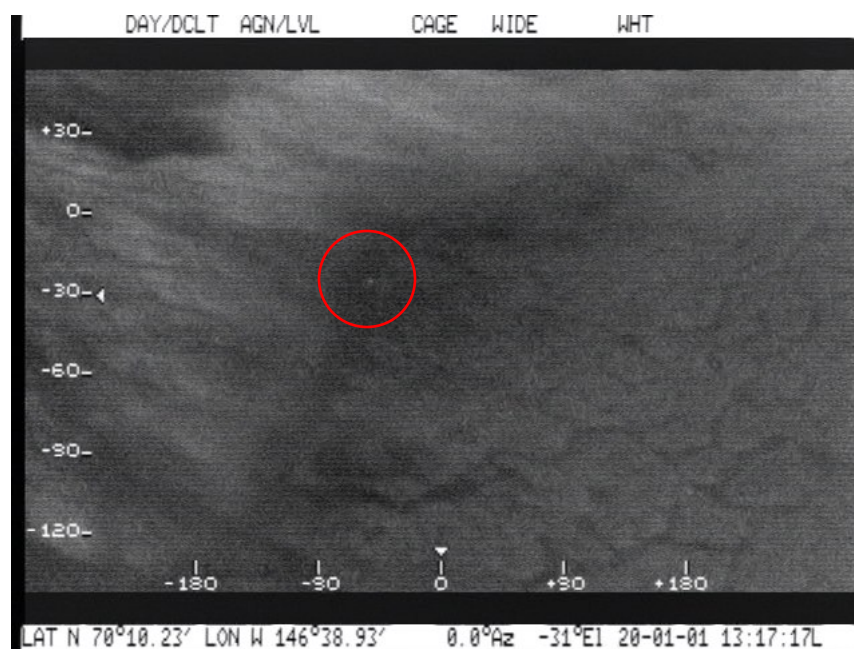


Figure 6: The faint glow of a known polar bear den along coastal bluff habitat.



Figure 7: The heat signature from a known polar bear den. This image is a little more difficult to discern the habitat features.



Figure 8: Faint image of a known den during a mission with some air moisture present.



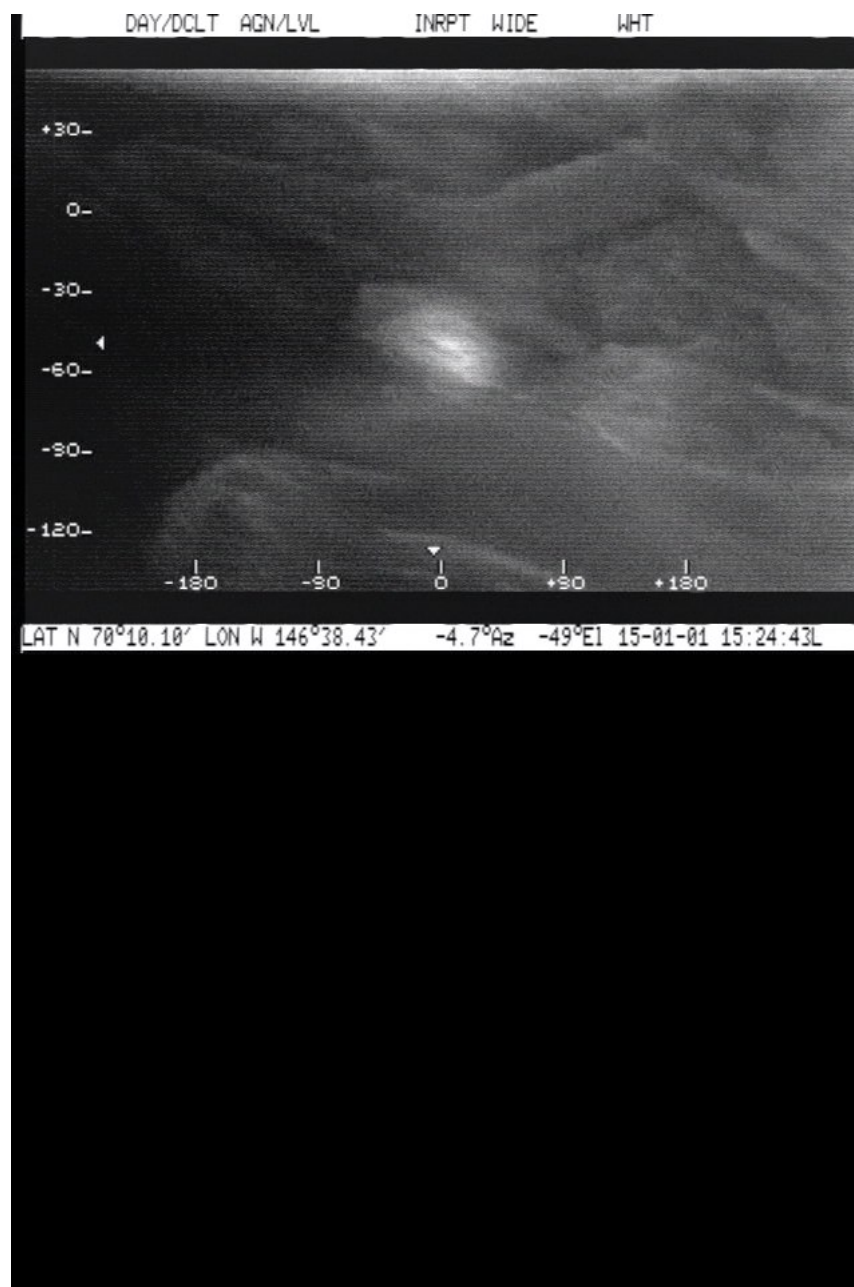


Figure 9: Two images of known dens in the narrow field of view mode of FLIR (zoom). In the lower image you can actually see what appears to be the entrance hole.



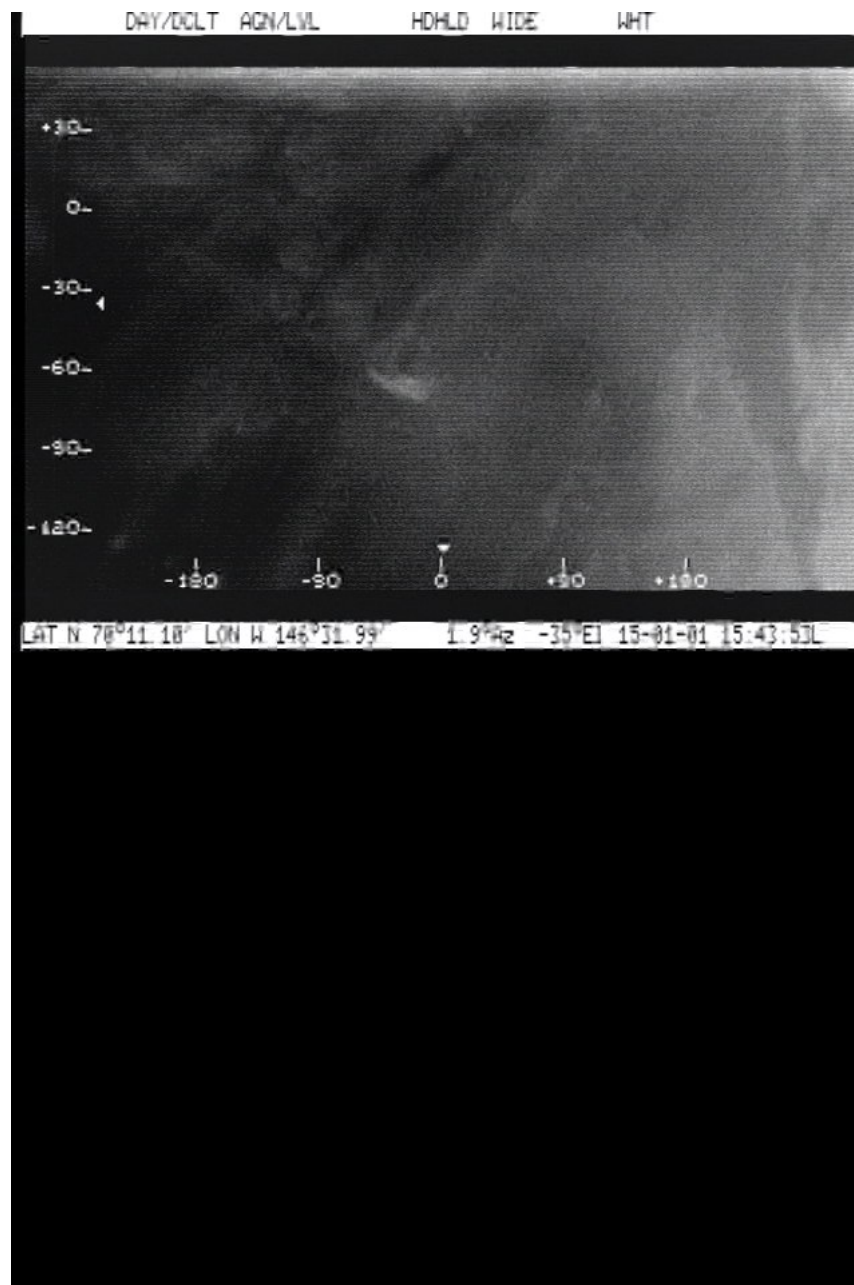


Figure 10: Two images of known dens in the narrow field of view mode of FLIR (zoom). The shape of the heat signature in the lower image actually reflected the internal geometry of the den structure.

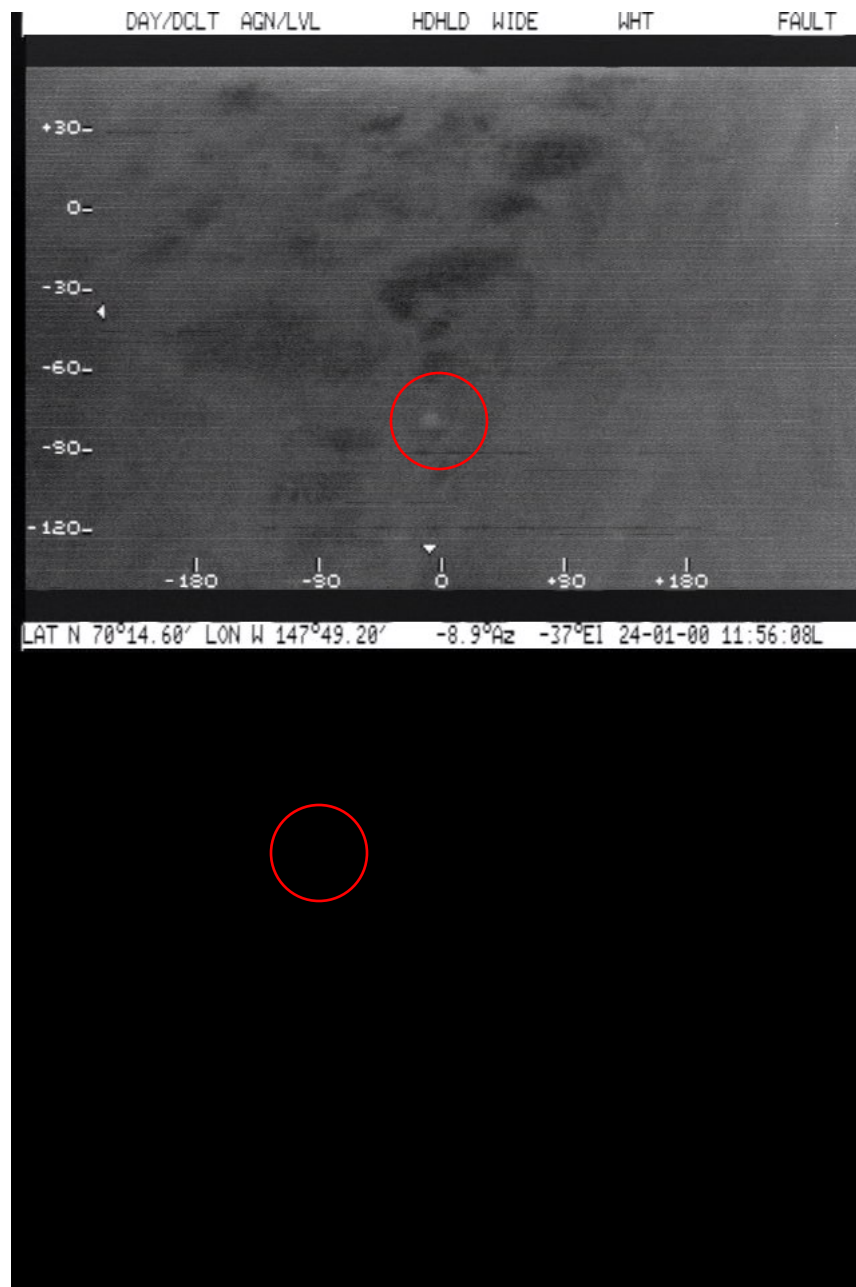


Figure 11: Dens are not always obvious as seen in these two FLIR images. The first image shown a den taken with an uncalibrated imager in poor weather conditions (It is surprising this is visible at all). The second image was taken under poor conditions (moisture visible in the air).

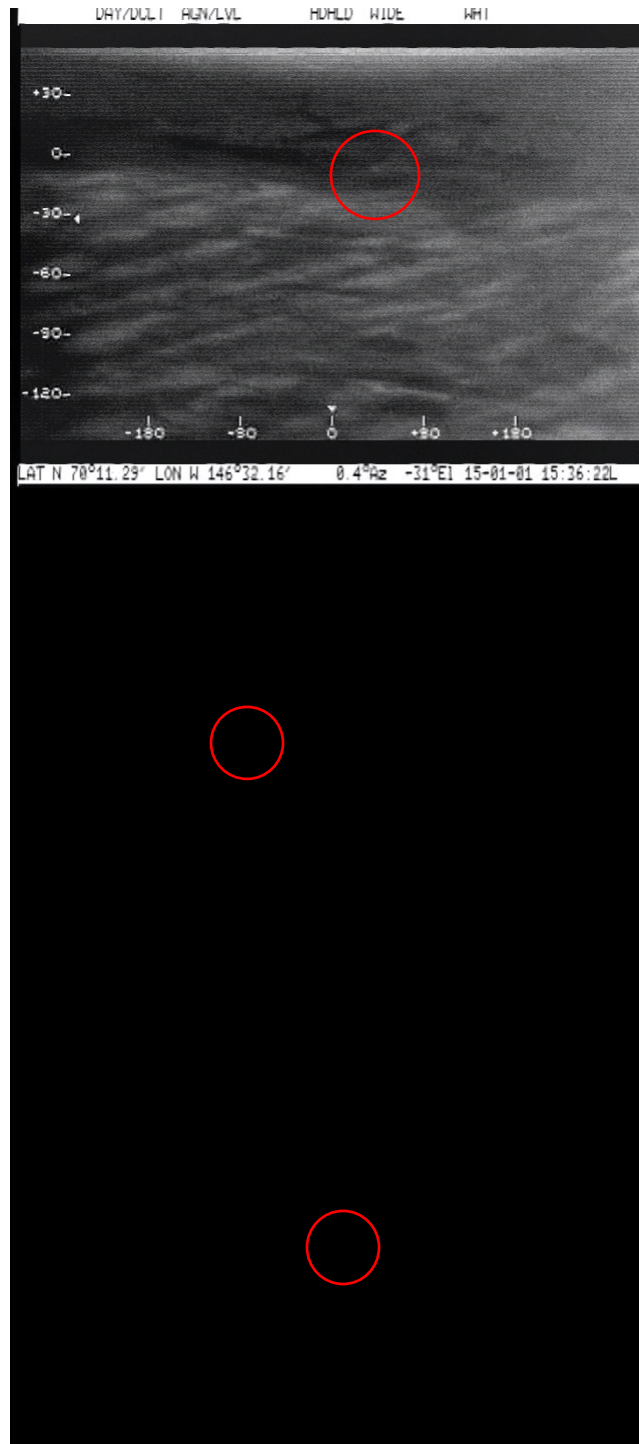


Figure 12: As noted in the protocol, the presence of air moisture is one of the most significant factors which limit FLIR effectiveness. The three images above are from the same den on different days and conditions. The first image is under good conditions and the second two were taken with fog (middle) and snow (bottom).

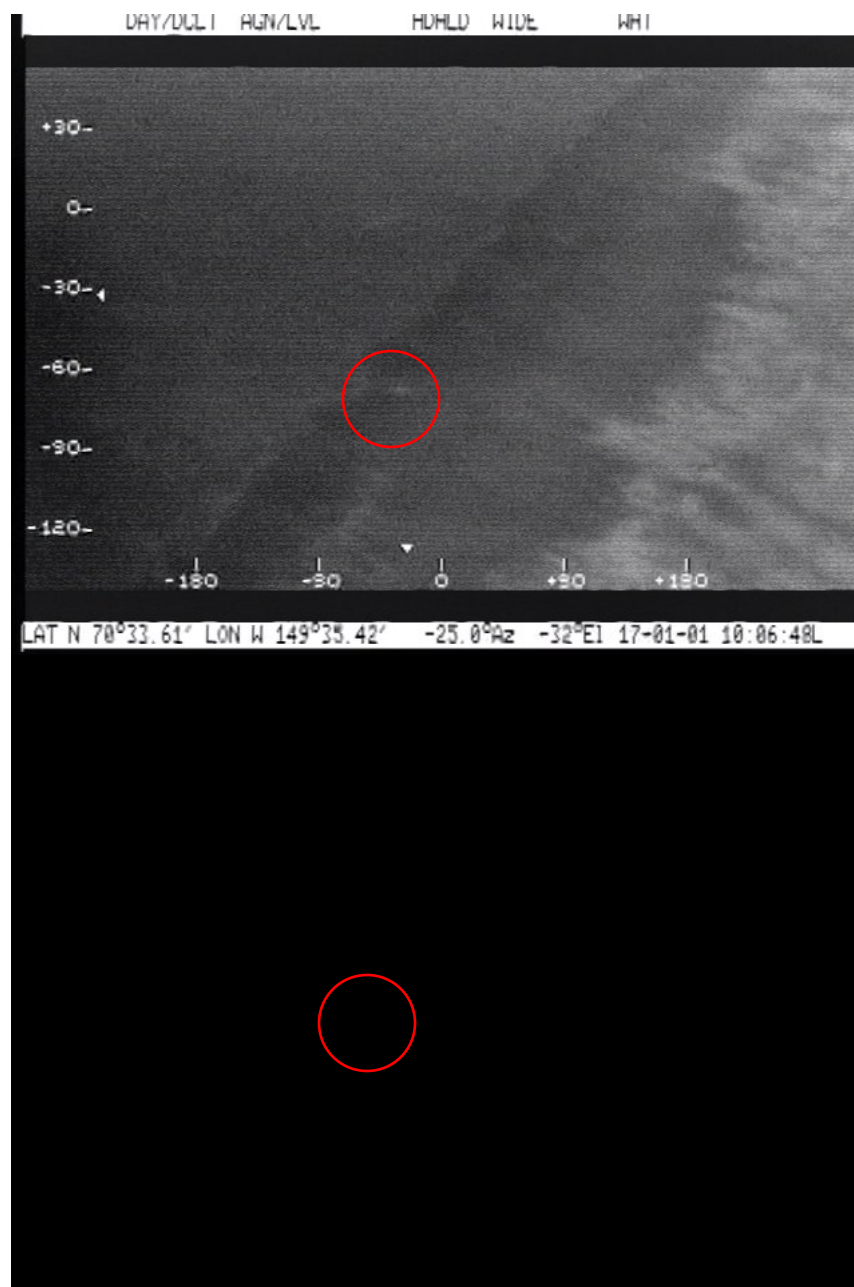


Figure 13a: Conditions can also change during a mission. The next two pages show images taken of the same dens on the same day. The difference is due to the presence of moisture in the air on the afternoon transects. For both sets the morning flight is above and the afternoon below.

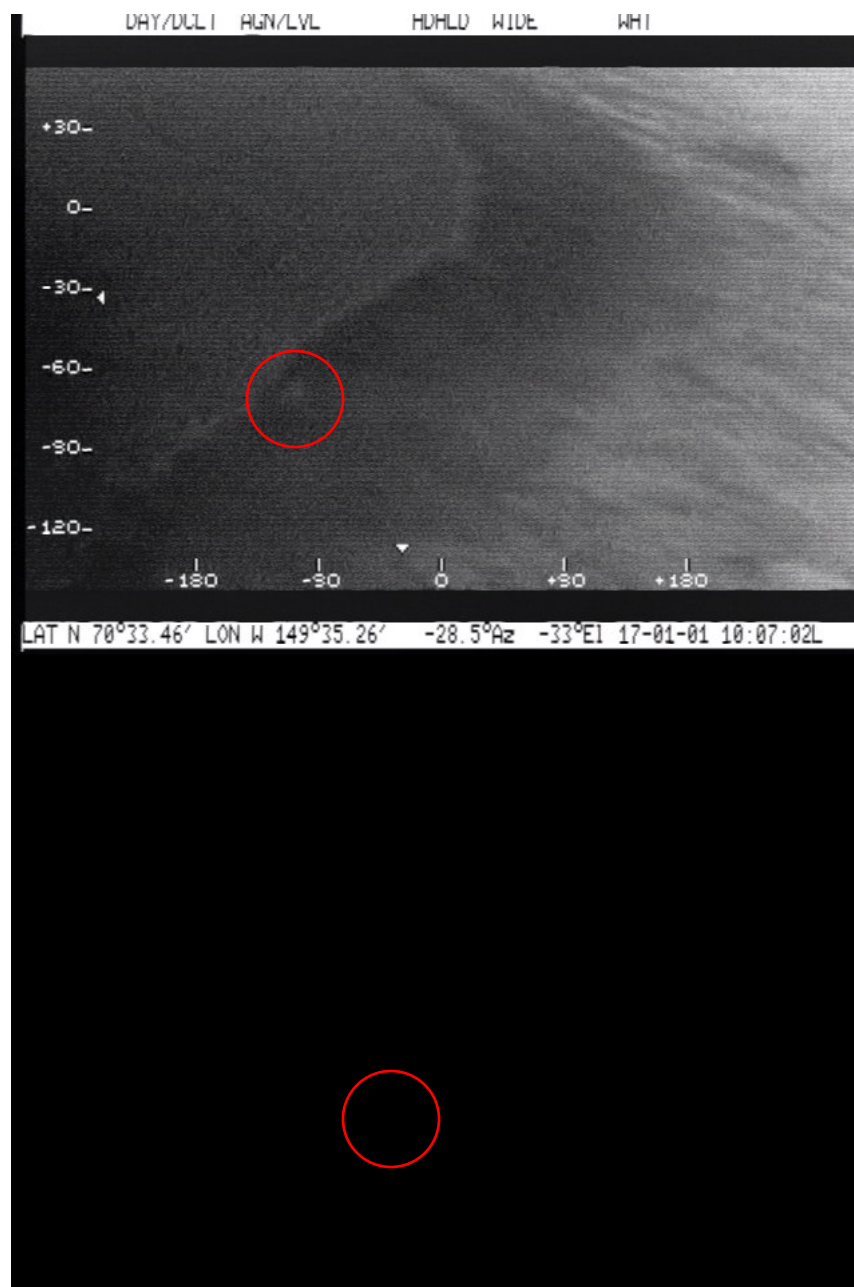


Figure 13b: Morning transect above, afternoon with moisture present below.

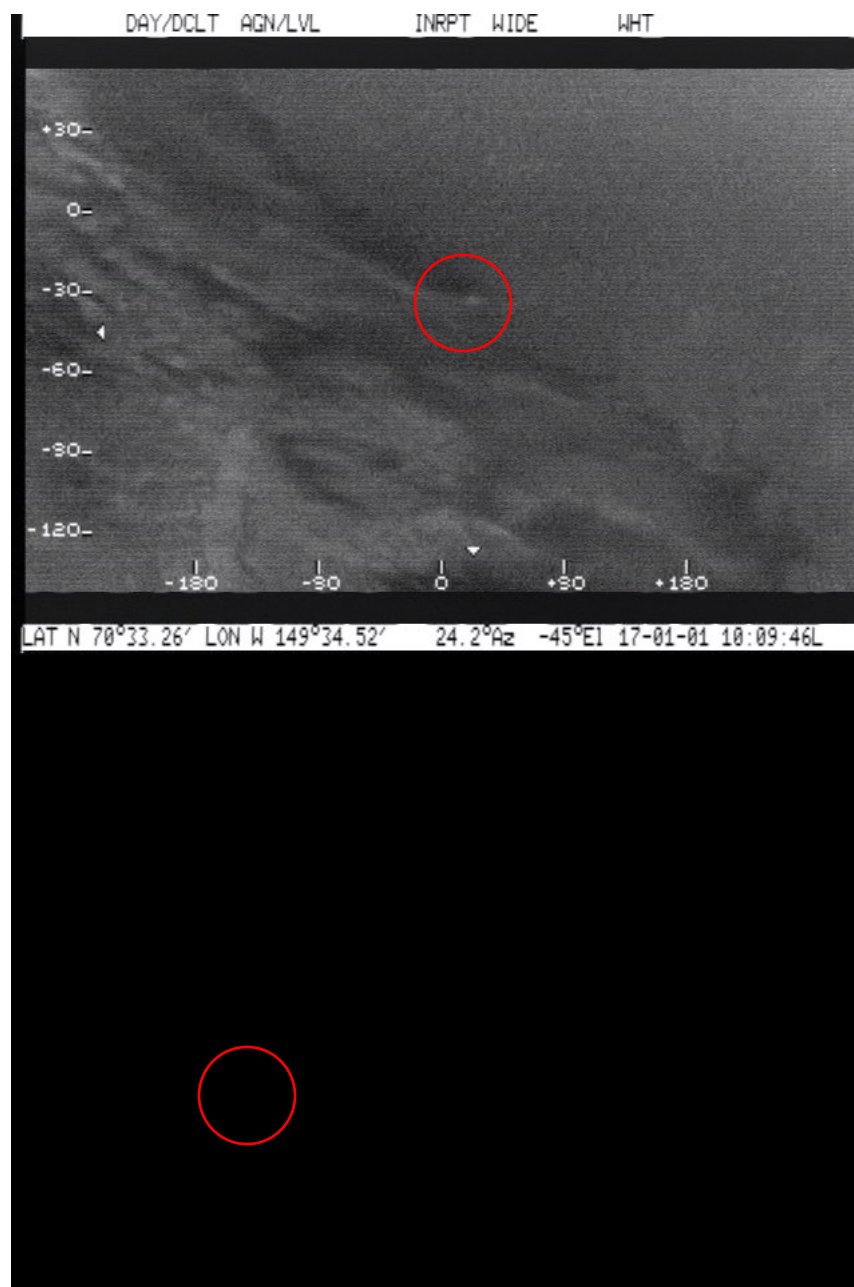


Figure 14: Transect orientation can also effect den detection with FLIR. In the above images the same den is surveyed first from East to West (top) and then from West to East (bottom).

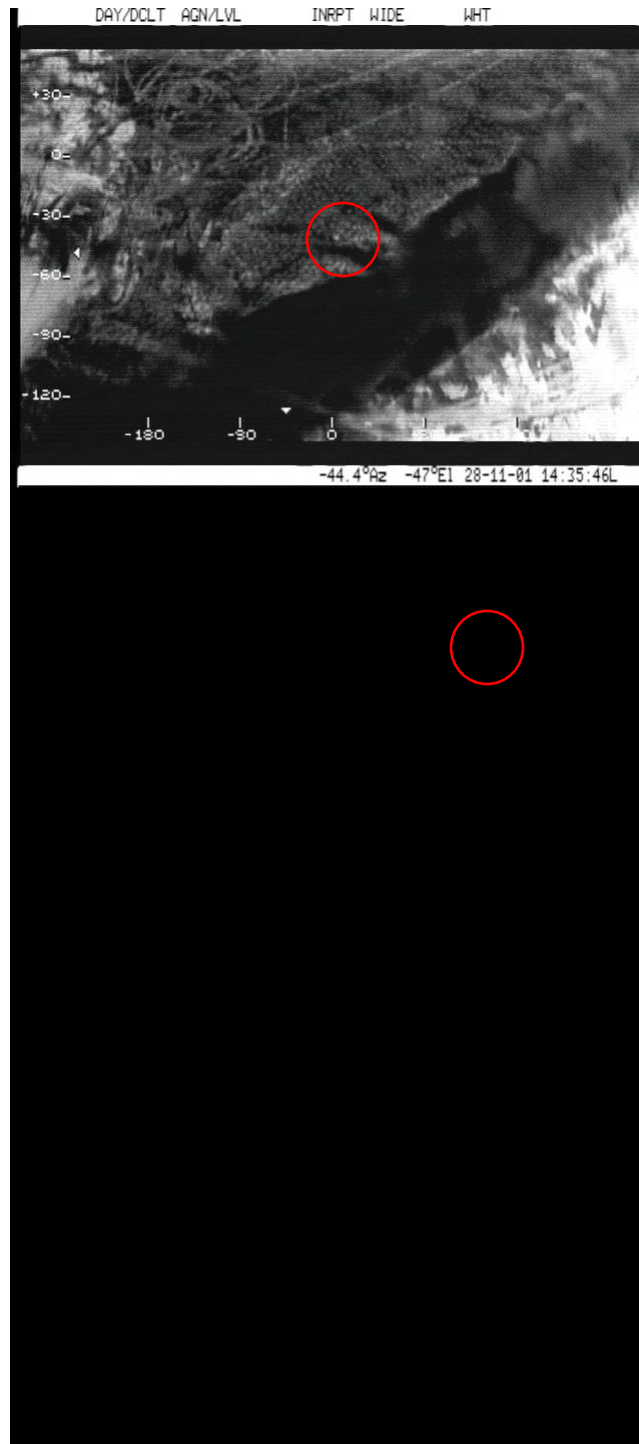


Figure 15: As mentioned in the protocol, polar bears den in drifts along bluffs. Hence, the location of a perceived hot spot is critical. The hot spot in the top photo is clearly on the tundra. In the middle photo, despite the poor viewing conditions, we see much the same thing. On closer inspection, this spot is actually a grazing caribou (bottom).





Figure 16: Be wary of hot spots near the bottom of bluffs or associated with linear features. The top image shows a beaded crack you would expect to see on sea or river ice. The middle photo shows several hot spots that are clearly below the bluff drift and associated with sea or river ice. The bottom image shows a classic hot spot, but it is associated with a linear feature and is on the flat sea ice where there is inadequate snow drifting.



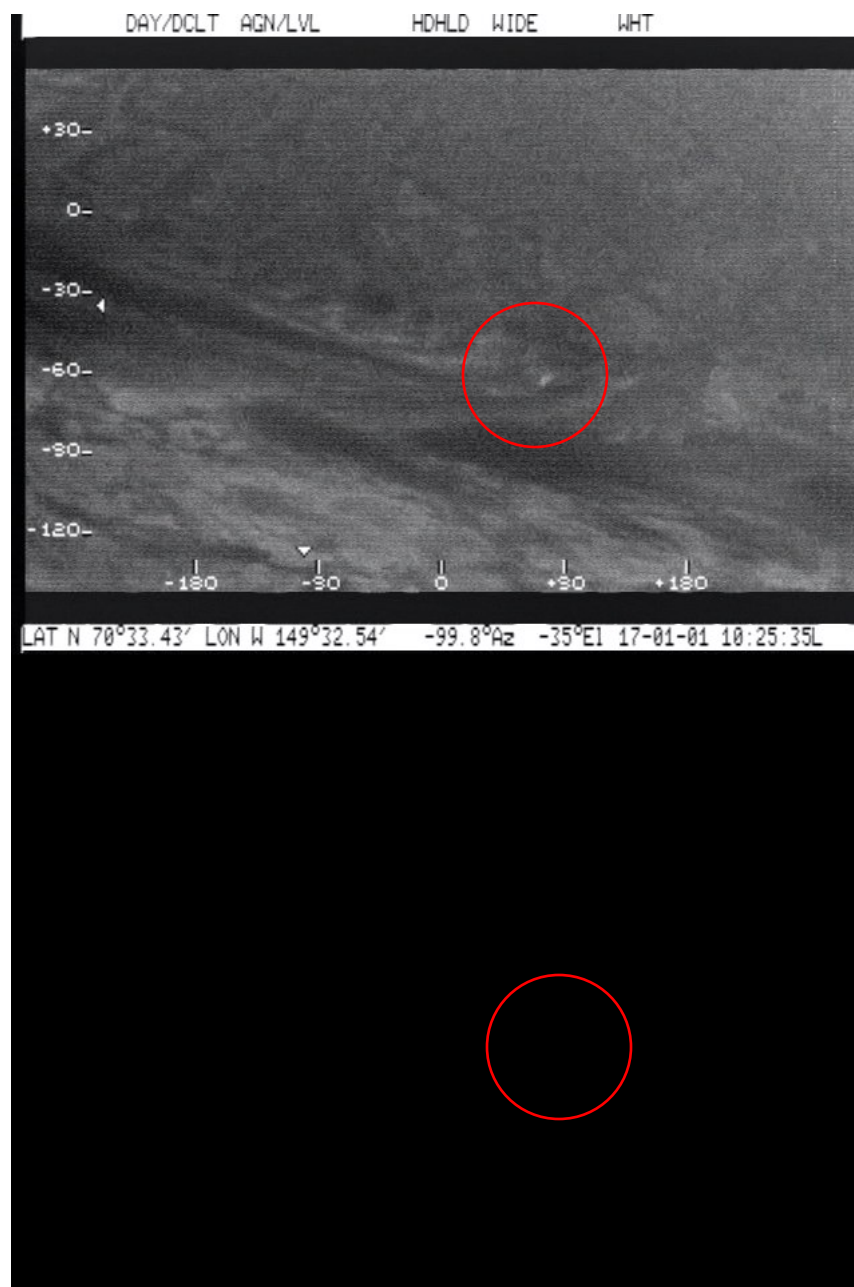


Figure 17a: Use a combination of video and FLIR to help weed out suspicious hot spots. The top image shows what appears to be a promising hot spot. The bottom image indicates the spot is merely the exposed soil of an eroding bank. The spot is also very high on the bank.

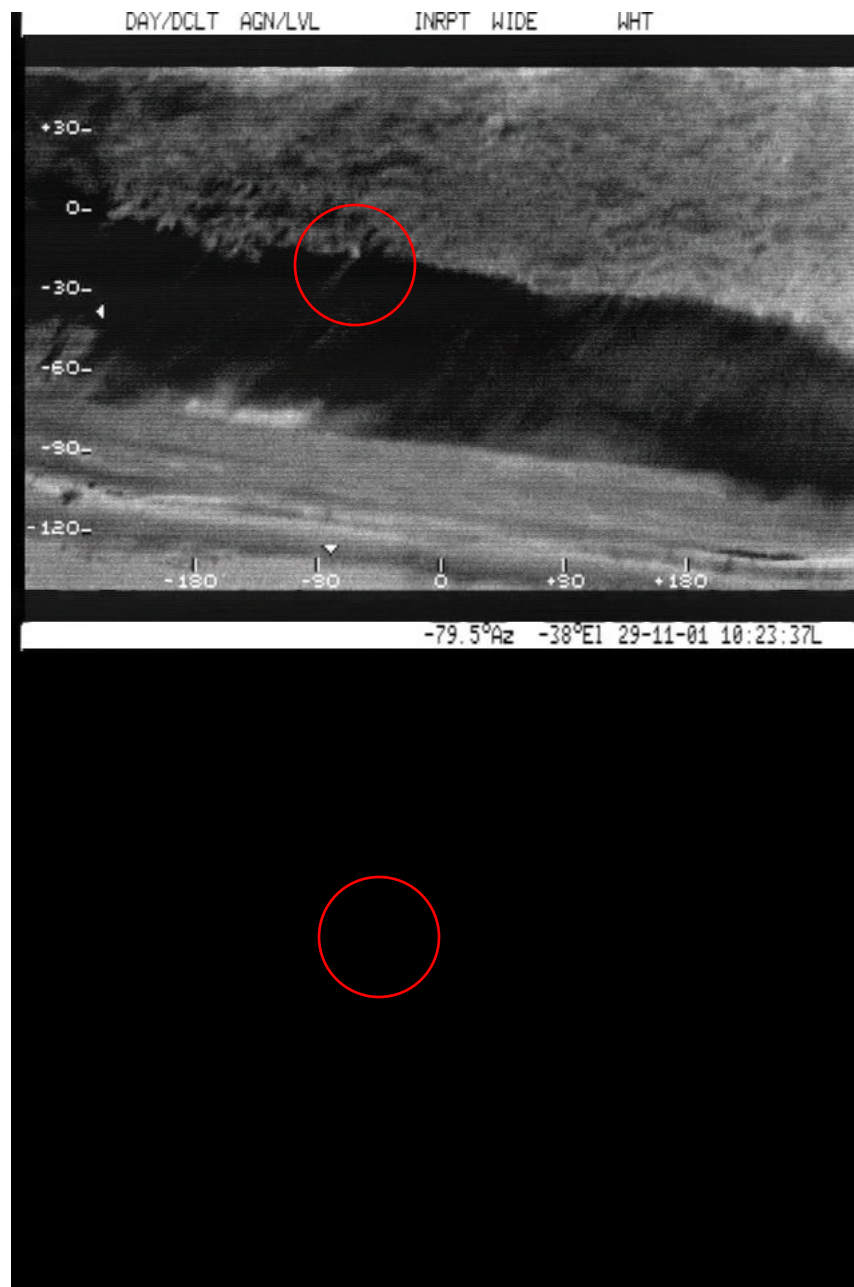


Figure 17b: The same can be seen in this series of FLIR and video imagery. The hot spot again appears to be exposed soil or a rock and is located much higher on the bluff than one would expect for a polar bear den.

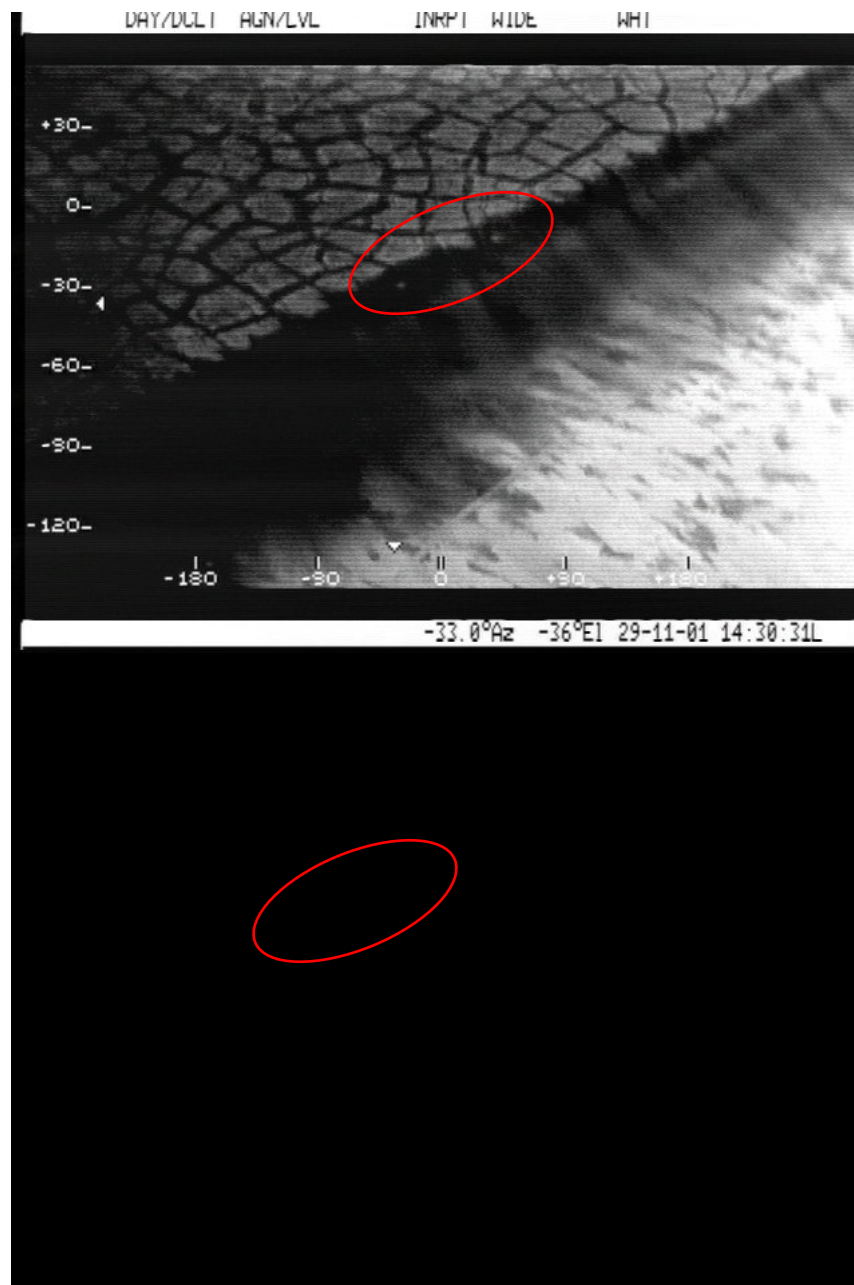


Figure 18: The video/FLIR combination does not always provide the answers as can be seen in this series of images. In this case, it would be best to hover down near the sights and look for any visual cues by looking directly out the window. These would be reasonable hot spots to identify as potential dens if there was no other evidence for the heat signatures.



Figure 19: The detrimental effects of sunlight can be clearly seen in these images. Anything that sits above the surface will begin to rapidly warm with the least amount of solar radiation. Such competing hot spots make it virtually impossible to detect dens under these circumstances. The top image shows vegetation along a river bluff and the bottom image is the same taken in narrow field of view.

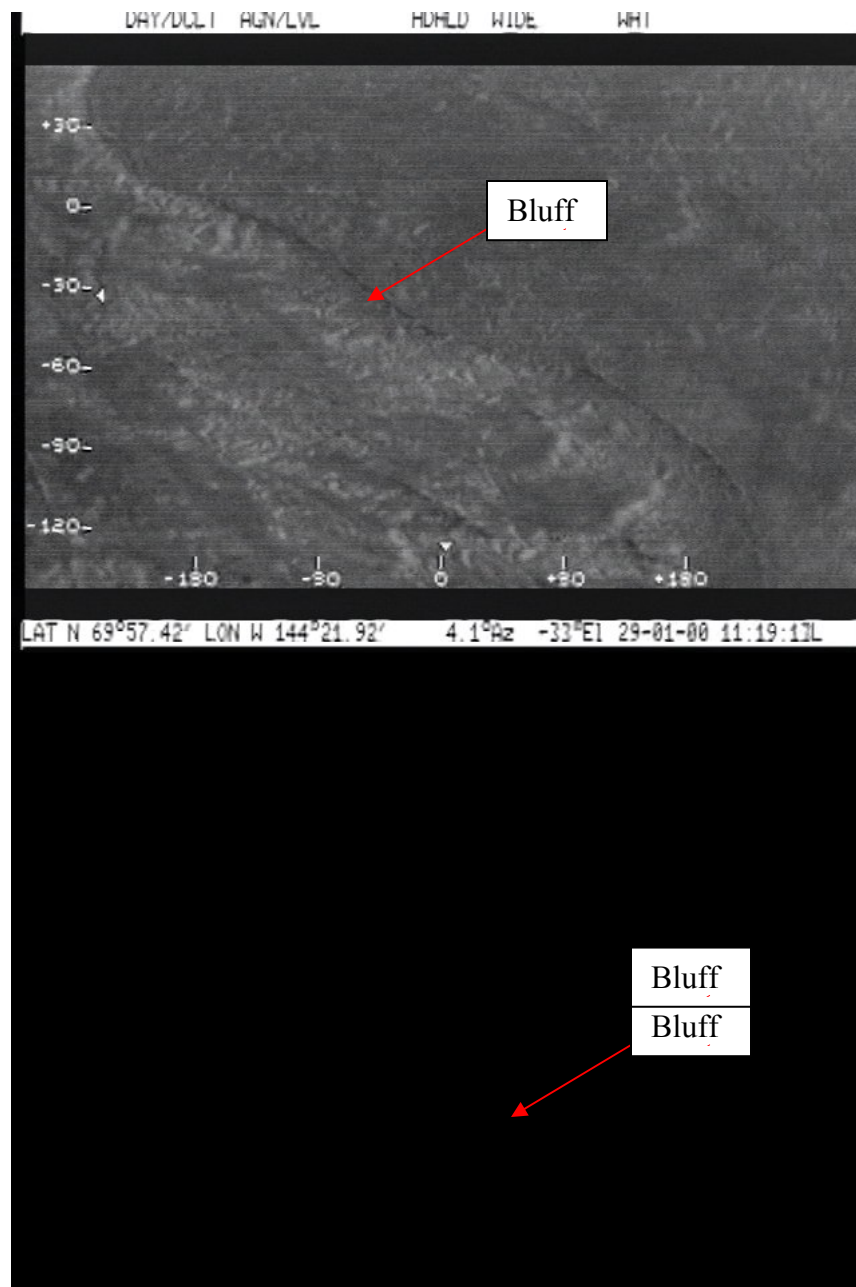


Figure 20: Sunlight can also make the landscape uniformly warm thereby lightening the FLIR image and making it more difficult to discern features and potential dens.

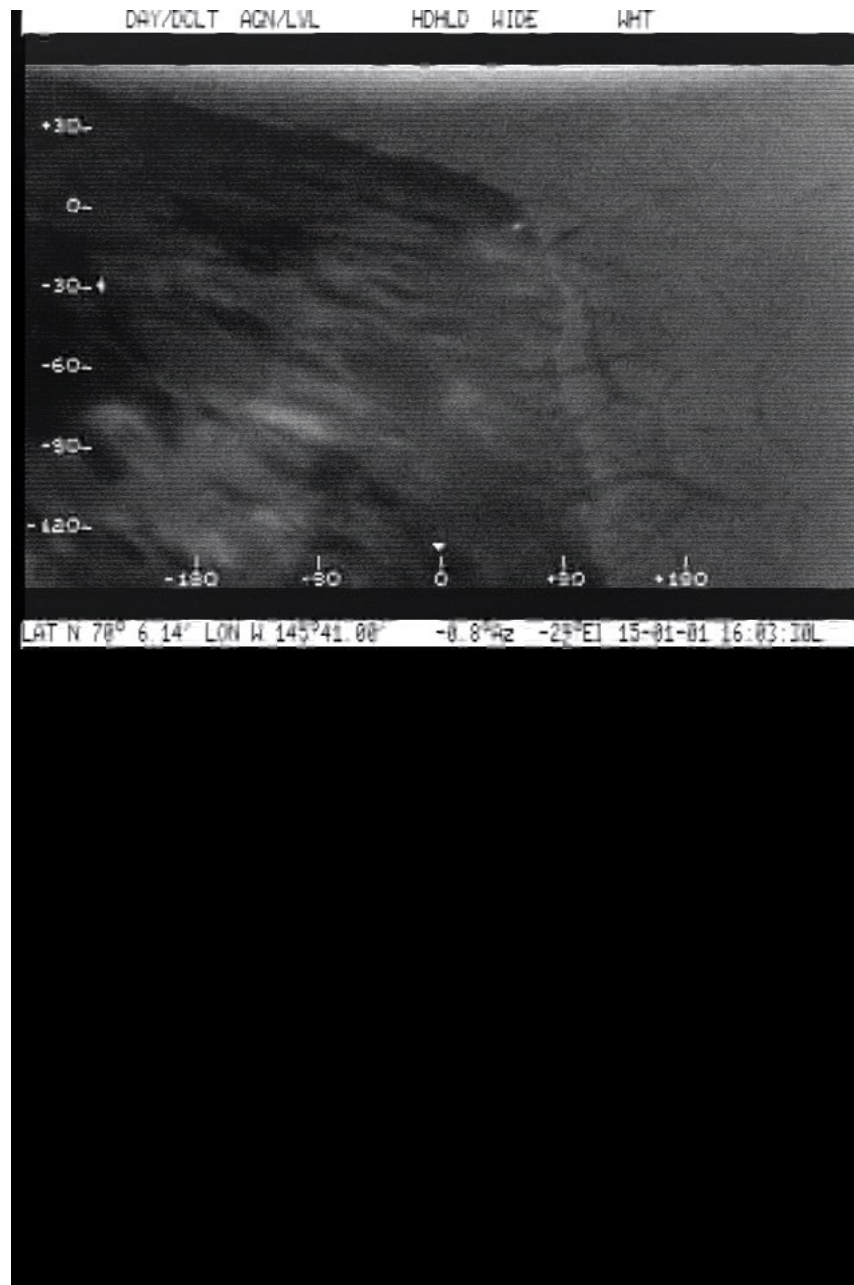


Figure 21: Very bright spots located in suitable habitat may indicate open dens as is evident in these images. In the bottom image you can actually see the footprints of a bear. Abandoning dens mid-winter is not uncommon although the reasons for this are poorly understood.

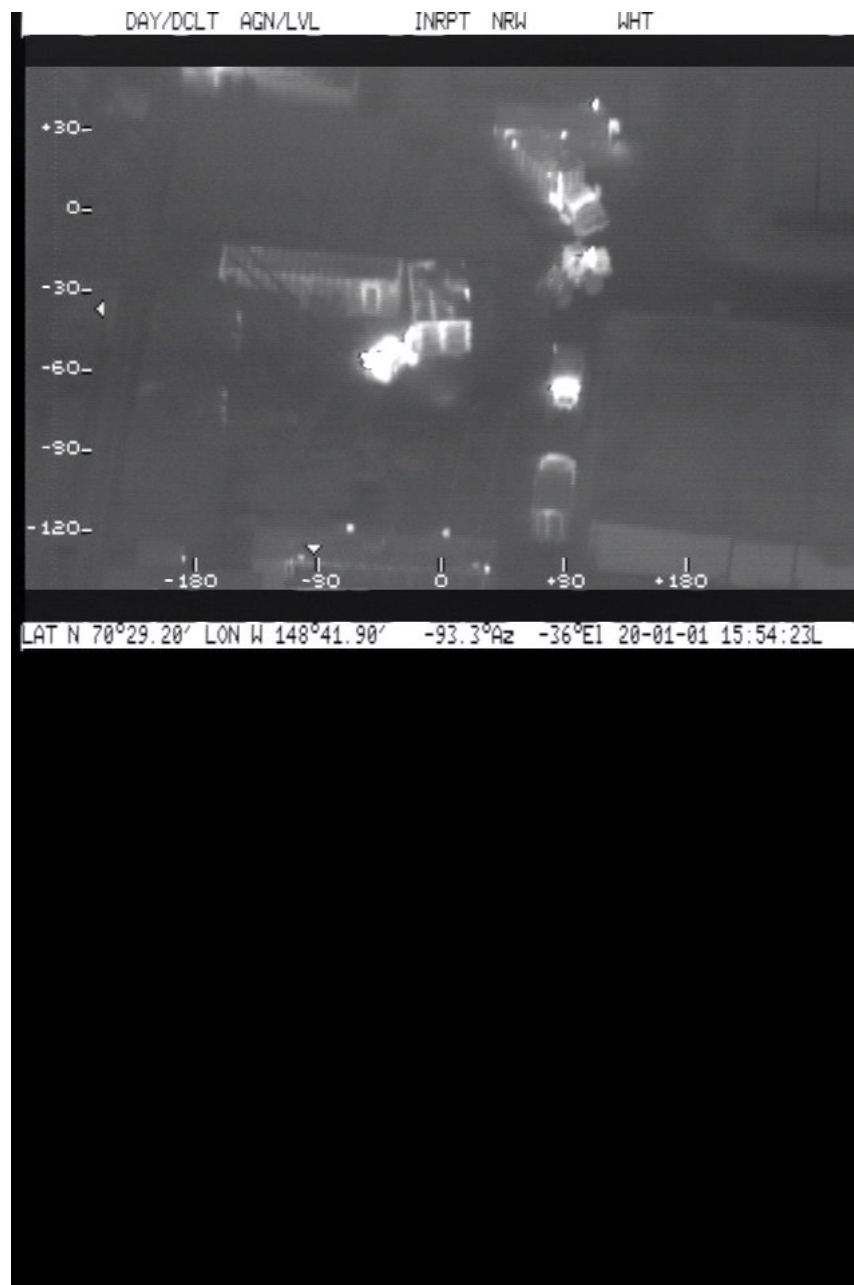


Figure 22: Man made objects, such as buildings and vehicles, are easily discernible with FLIR and make excellent targets for practice and FLIR calibration as you depart the airfield and head towards the target area. If you cannot see man made targets with the FLIR, something is wrong-check the weather and your equipment before proceeding any further!





Figure 23: Surprisingly, polar bears themselves are also quite visible with FLIR!



## **APPENDIX 2**

### **FLIR CONTACT LIST**

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